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Using Phylogenetic Analysis To Diagnose Freshwater Molluscan Species In The Judith River Formation Of Hill And Fergus Counties, Montana, With Notes On Depositional Environments And Quality Of Preservation

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USING PHYLOGENETINC ANALYSIS TO DIAGNOSE FRESHWATER MOLLUSCAN SPECIES IN THE JUDITH RIVER FORMATION OF HILL AND FERGUS COUNTIES, MONTANA, WITH NOTES ON DEPOSITIONAL ENVIRONMENTS AND QUALITY OF FOSSIL PRESERVATION

by

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This thesis, submitted by Matthew Michael Illies in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota, has been read by the Faculty Advisory Committee under whom the work has been done and is hereby approved.

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Name of Committee Member

Name of Committee Member

Name of Committee Member

This thesis is being submitted by the appointed advisory committee as having met all of the requirements of the School of Graduate Studies at the University of North Dakota and is hereby approved.

~~Wayne Swisher~~ Dean of the School of Graduate Studies

May 8, 2017

Date

PERMISSION

Title	Using Phylogenetic Analysis to Diagnose Freshwater Molluscan Species in the Judith River Formation of Hill and Fergus Counties, Montana, With Notes on Depositional Environments and Quality of Preservation
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Matthew Illies

May 05, 2017

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To Mark Rakke,

Who showed me fossils exist outside of books.

ABSTRACT

The Judith River Formation has a long history of study, from Meek and Hayden's expeditions in the 1850s to E. D. Cope's searches for new dinosaur species. More recently, the Judith River Formation receives a plethora of research in paleontology and geology. Despite this, little work has been done on the freshwater molluscan fauna found within. The purpose of this study was to create a method where accurate species diagnoses become possible, and to create a launching point for future work in the Judith River Formation. Freshwater mollusk specimens were collected from shell beds in the Judith River Formation at the type area in the Missouri River Breaks (Fergus County), and near Rudyard, Montana (Hill County). Specimens were then separated by general morphology and measured for select character traits (e.g. convexity of whorls). Photos of Judith River Formation type specimens were taken at the National Museum of Natural History at the Smithsonian Institution and subsequently measured for the same character traits. A table was created which listed possible character traits for the freshwater mollusk types and each possible outcome was given a code (e.g. 0, 1, 2) for analysis. Then using trait codes assigned to each type species and comparing them to trait codes assigned to collected specimens, species identifications were made. This methodology allows for a more quantitative method of species diagnoses. Accomplishing this is essential to additional cladistical work in the Judith River Formation as better material becomes available. Depositional environment of localities sampled was derived from autecological and lithologic data. This will be beneficial to both paleontologists and geologists for future work in the Judith River Formation

INTRODUCTION

The purpose of this study was to identify depositional environments using freshwater continental mollusks from two Judith River Formation outcrop areas. The first area sampled was the type area (Fergus County) of the Cretaceous Judith River Formation. The species named from this section represent most of the molluscan type specimens known from the formation and the corresponding time interval. Biostratigraphic work was never completed for the specimens collected by F.V. Hayden and species subsequently named by F.B. Meek and Hayden from the type area or elsewhere in the Judith River Formation. A number of geologists and paleontologists (e.g., White, 1874, 1883; Cope, 1876) examined the area soon after Hayden because of interest in dinosaurs and the desire to resolve chronostratigraphic issues that persisted into the early 1900s (e.g., Stanton, 1903, 1905; Sternberg, 1914). The second study area is on land owned by Dan Redding in Hill County, Montana, not far from the Canadian border. The Judith River Formation outcrops examined occur in Kennedy Coulee located north of the farm. Kennedy Coulee exposures have been under study since the 1980s primarily by the University of California Museum of Paleontology and more recently by the Museum of the Rockies for Campanian mammal and dinosaur fossils (Freedman and Fowler, 2010; Freedman, Tanke and Wolff, 2012; Freedman and Wilson, 2005, 2006; Freedman, 2008, 2009; Goodwin, 1990; Goodwin and Deino, 1989).

This study used morphometric analysis to make species identifications for specimens collected at the two areas. Fossil continental mollusks are notoriously difficult to identify, especially as they are frequently incomplete, deformed, and/or replaced with other chemical compounds. Using measurements laid out in Hartman (2015), hard part character traits can be determined and used in phylogenetic analyses. Accurate identifications are the basis of meaningful paleoautecological interpretations. Independence of character traits is important for character trait analysis. Because of this, only selected traits are available for the analysis. This study looked to expound upon which continental molluscan traits are meaningful when using a phylogenetic methodology to determine species, as these have yet to be established for Judith River Formation taxa. Normally, phylogenetic studies aim to establish relationships between species using homologous traits and parsimony (Grandcolas, 1994), but this study used possible homologies to diagnose species. If two specimens share either all or a majority of synapomorphies, then they should be placed together on the phylogenetic tree, as the tree assumes these are homologous.

Paleoautecology, how fossil animals or species interacts with ancient environments, was used extensively in paleontology, especially with invertebrates (La Rocque, 1960; Hanley, 1969; Cortijo et al., 2014). Autecology allows researchers to take an ecological approach to depositional environment designation in addition to lithostratigraphic work through prior understanding of molluscan ecology. In a paleontological context, living species of a genus determine the preferred habitats of extinct species of the same genus. Paleontologists apply this same method to extinct genera by using extant genera. Aided by the work by Rogers (Rogers, 1994, 1998; Rogers et al., 2016), this study used autecology of molluscan fossils found in the Judith River Formation to add to the history of the depositional environment at a locality scale. Paleontologists can use autecological data in identifying depositional environment and taphonomy of vertebrates and invertebrates and expand this work to additional localities and contemporaneous rocks like the Belly River Group. With an understanding of how these mollusks interact with their preferred environment, we can better assess the occurrence of mollusks in certain depositional settings.

Geologic History

The first reference to rocks now known as the Judith River Formation occurred in Meek and Hayden (1856), where Hayden referred to them from his mid-1850s explorations as the "estuary beds". The area Hayden explored is located along the Missouri River and creeks that empty from it in the Missouri Breaks National Monument in north-central Montana. After additional exploration and publication (Meek and Hayden, 1857, 1860, 1861), Hayden assigned the name Judith River Group to these beds (1871, p. 97):

> [T]he Missouri River which has already yielded many fossils of great interest, but which seems to be isolated from the others. This is what I have called the Judith basin, and inasmuch as it seems to be one, of the ancient lake deposits, and characterized by a peculiar group of organic remains, I will designate the strata as the Judith Group.

Eldridge (1888, 1889) formally added the Judith River beds into the Montana Group. In the early 1900s, debate ensued over the age of the Judith River beds (Stanton, 1902, 1904; Hatcher, 1903; and Osborn, 1903). In 1903 and 1905, Stanton and Hatcher placed the Judith River Group between the Claggett Formation (below) and the Bearpaw Formation (above). As debate continued on the age of the "Judith River Group", authors began to refer to it as the

"Judith River Formation" (Lambe, 1907; Stebinger, 1914; Bowen, 1915). Since these early publications, contributions to the geology and vertebrate paleontology of the Judith River Formation in both Montana and Alberta included Sternberg (1914, 1915, vertebrates, Montana); Weimer (1960, 1963, stratigraphy, Montana); Ostrom (1964, vertebrates, Montana); Mclean (1971, stratigraphy); Wood et al. (1988, vertebrates, Montana); Wood (1989, vertebrates, Montana); Brinkman (1990, vertebrates, Alberta); Eberth (1990, 2005, stratigraphy, Alberta); Eberth and Hamblin (1993, stratigraphy, Alberta); Rogers (1994, 1998); Rogers et al. (2016, stratigraphy, Montana).

Part of Stanton and Hatcher's (1904) Judith River Formation study was to settle correlation problems that appeared to exist between Montana and the Canadian Belly River Group section. Although resolved to their satisfaction, more precise chronostratigraphic studies reopened the issue of equivalency. Recent improvements in radiometric dating methods, along with a few new dates, have resulted in more exact age estimates for parts of the Judith River Formation. A tentative numeric framework now exists to compare Montana with Alberta section based on isotopic dates (Goodwin and Deino, 1989, Montana; Eberth, 2005, Alberta; Rogers et al., 2016, Montana).

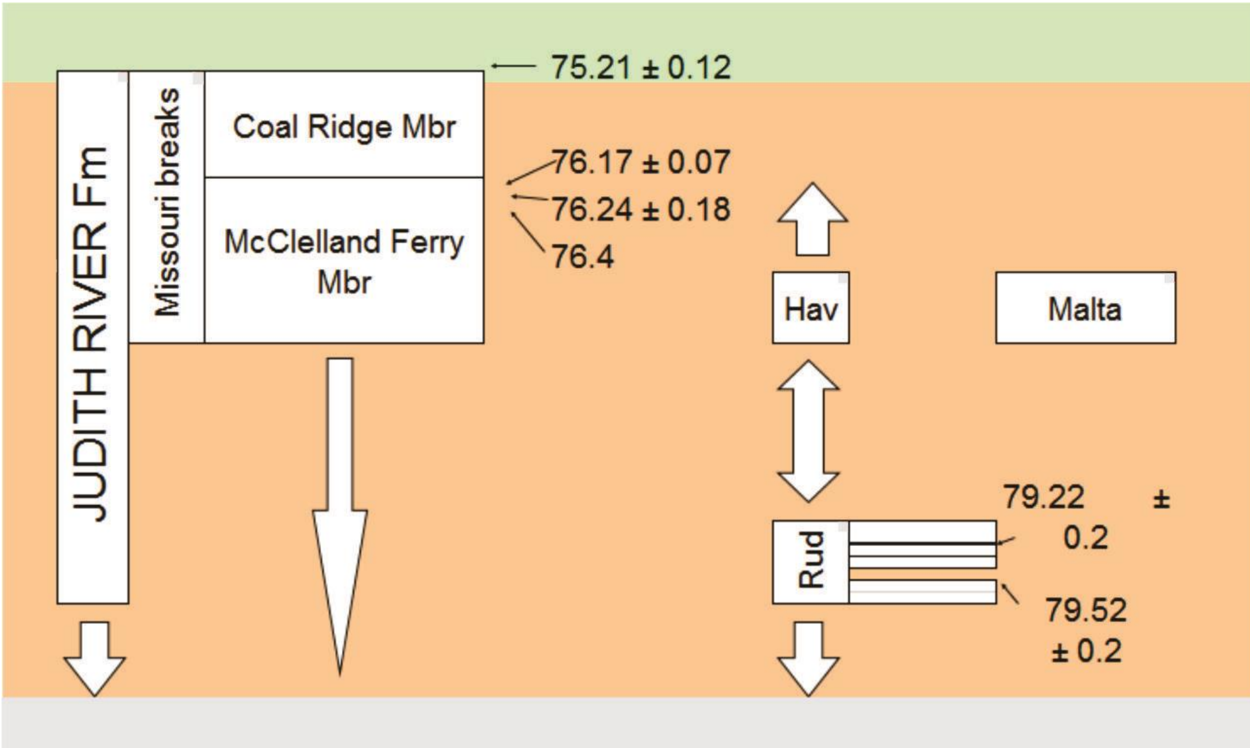


Figure 1. Correlation of the Judith River Formation from the type area in the Missouri Breaks to Kennedy Coulee near Rudyard, Montana. Dates in millions of years (Ma). Figure after Fowler (2016).

Geologic Setting

The Upper Cretaceous Judith River Formation in its type area in the Missouri Breaks of Montana occurs in badlands topography and averages 180 m in thickness (Rogers, 1998). To the west, the Judith River Formation grades into the Two Medicine Formation (Fig. 1). The type area of the Judith River Formation exists approximately 30 miles northwest of the town of Winifred Montana. Kennedy Coulee is located 20 miles North of Rudyard, Montana.

$^{40}Ar/^{39}Ar$ analyses of bentonite beds interbedded within continental facies of the Judith River Formation are consistent with a Campanian age designation (Goodwin and Deino, 1989; Rogers et al., 1993; Rogers and Swisher, 1996). The Judith River Formation was deposited over approximately three million years and is the type interval for the Judithian North American Land Mammal Age (NALMA) (originally named by Russell, 1964, 1975).

The lowest unit of the Judith River Formation present in its type area is the Parkman Sandstone Member (Gill and Cobban, 1973), which consists of tan sheet siltstone and sandstone bodies. The Parkman Sandstone Member represents shoreface and foreshore deposits (Rogers, 1998).

Overlying the Parkman Sandstone Member, Rogers et al. (2016) subdivided the Judith River Formation in its type area into two continental members (Coal Ridge and McClelland Ferry) and an overlying marine member (Woodhawk), which occurs on the eastern margin of the progradational tongue of the Judith River Formation. Rogers et al. (2016) described the 90-m thick Coal Ridge Member as a mudstone-dominated alluvial secession with dark gray to olive green smooth slopes, with thin fine-grained sandstone bodies. It contains abundant beds of lignite ironstone, bentonites, fossils, and microfossil bonebeds. The depositional environment of the Coal Ridge Member is a coastal plain alluvial (Rogers, 1994, 1998; Rogers and Kidwell, 2000; Rogers et al., 2016) that thins eastward into the Woodhawk Member. The overlying McClelland Ferry Member is approximately 70-m thick and consists of sandstone-dominated alluvial settings, with gray to pale yellow blocky exposures that form multistory bodies and sheet-like geometry. The McClelland Ferry Member is a fluvial, floodplain, and coastal mire facies that accumulated landward of the Parkman Sandstone Member (Rogers, 1998; Rogers and Kidwell, 2000; Rogers et al., 2016).

Stratigraphy in Kennedy Coulee differs slightly from that of the type area, and Fowler (2016) recommends using the Canadian stratigraphic divisions defined by Eberth (2005). The formations in ascending order are the Foremost, Oldman, and Dinosaur Park (Fig. 2) (Fowler, 2016).

Ogunyomi and Hills (1977) suggested the Foremost Formation consists of four freshening upwards environments: offshore transition, barrier island, lagoon/salt marsh, and freshwater marsh. Fowler (2016) stated the Judith River Formation in Kennedy Coulee is likely equivalent to the Foremost Formation and the lowest unit of the Oldman Formation.

The top section of exposures at Kennedy Coulee is likely correlative to the Oldman Formation, which overlies the Foremost Formation. Three formal units subdivide the Oldman Formation. The bottom and top units comprise of isolated channel-fills, while the middle Comrey Sandstone (Troke, 1993), consists of many grouped channel-fills (Eberth, 2005).

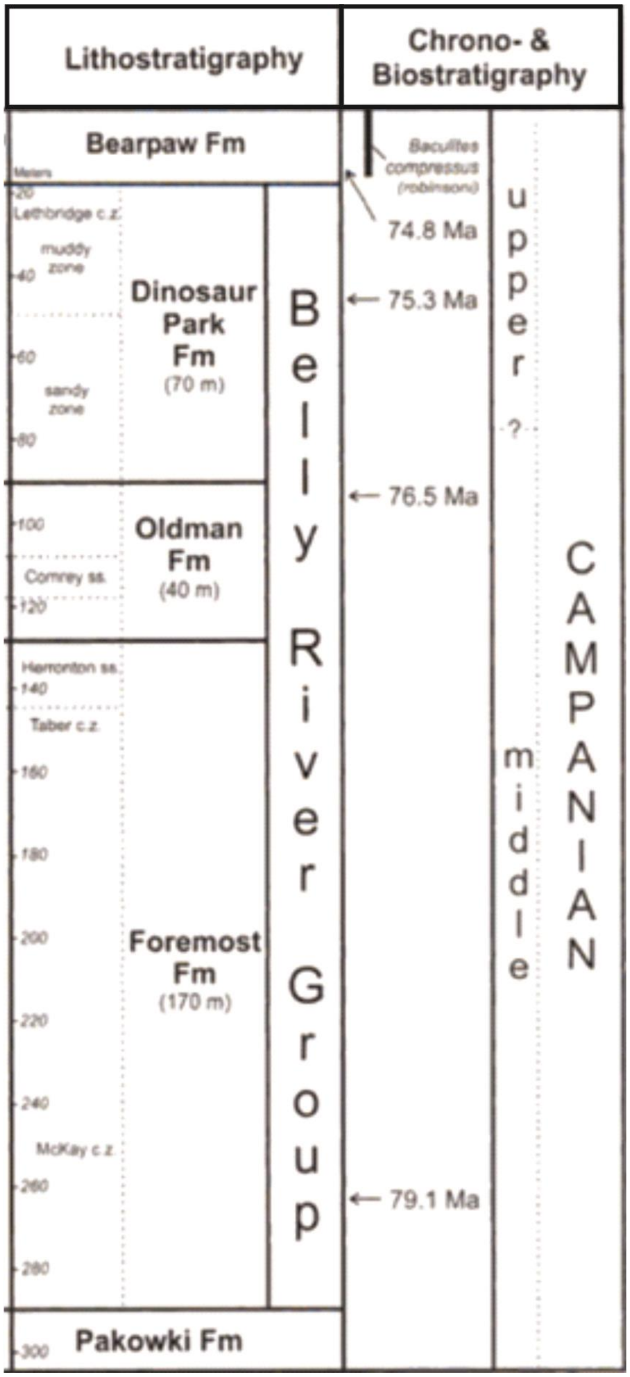


Figure 2. Stratigraphy of the Canadian Belly River Group in outcrop in Dinosaur Provincial Park, Alberta (Eberth, 2005).

Systematics

The systematic section is in two parts, Gastropoda and Bivalvia, and further by respective families as interpreted from identified genera. The ecology of each is described from summed various sources. Annotations about the primary and secondary types follow quotes of the original species descriptions. Later species/specimen analyses use these annotations and other observations.

Class Gastropoda

Family Helicidae

Genus *Helix* Linnaeus, 1758

Ecology. Snails of the genus *Helix* are terrestrial, inhabiting woodlands and grasslands. Some species prefer loose soil in which to hibernate (Pollard, 1975).

"Helix" occidentalis Meek and Hayden, 1857

Plate VI, Figures 42a, b

Original Description.

> Shell thin, rather small, depressed nearly orbicular; volutions four, convex above, prominent, or almost subangular a little above the middle of the outside, gibbous below, most convex near tile umbilicus; surface ornamented by regular rather strong oblique lines of growth; suture well defined; umbilicus deep, less than one-third the transverse diameter of the shell, exhibiting most of the inner, volutions; aperture round oval, modified slightly by the succeeding whorl; lip sharp, not reflexed. Greatest transverse diameter .33 inch [8.39 mm]; height .21 inch [5.33 mm]; greatest diameter of aperture .16 inch [4.07 mm] (Meek and Hayden, 1857, p. 137).

Annotated Description. Shell dextral, small (4.38 mm in height) and depressed in shape. Number of measured whorls is 3.81. Spire is depressed, comprising 16% of the shell. Measured MSA is 120.61˚. Measured SWA is 134.89˚. Shell whorls are rounded above, and somewhat angular below. Sutures are deep and well defined. Shell has a deep umbilicus, and aperture is round to ovate in shape. Parietal lip is weak and not reflexed and basal lip is strong and not reflexed.

"Helix" vitrinoides Meek and Hayden, 1857

Plate VI, Figure 41

Original Description.

> Shell subglobose; spire elevated; volutions about four, convex, increasing rather rapidly, last one somewhat ventricose, contracted a little near the lip; suture distinct; umbilicus very small or closed; aperture oval or ovate; (lip reflexed?); surface unknown. Height .37 inch [9.4 mm]; breadth .44 inch [11.18 mm]; greater diameter of aperture .27 inch [6.86 mm]; smaller do. .20 inch [5.08 mm] (Meek and Hayden, 1857, p. 309).

Annotated Description. Shell is dextral, small (10 mm in height) and subglobose in shape. Number of measured whorls is 4.87. Spire is elevated, comprising 7% of total height. Measured SWA is 112.71°. Measured MSA is 101.99°. Shell whorls are convex and sutures are distinct and impressed. Umbilicus is closed, and aperture is ovate in shape.

Family Hydrobiidae

Genus "*Hydrobia*" Hartmann, 1821

Ecology. *Hydrobia* tends to prefer lacustrine environments (La Rocque, 1960), and estuaries and intertidal mudflats (Orvain and Sauriau, 2002). Taylor (1954) found specimens of *Hydrobia* in springs in the San Bernardino Mountains.

“Hydrobia” recta White, 1876

Plate V, Figure 30

Original Description.

> Shell small, very slender, sides of the spire straight; volutions convex, apparently twelve or more, increasing regularly and uniformly in size from apex to aperture. Surface marked by the ordinary lines of growth (White, 1876, p. 132).

Annotated Description. Shell is dextral, small (4.96 mm to7 mm in height), elongate conic in shape. Number of measured whorls is 6.24. Spire is very elevated, comprising ~55% of the shell. Measured MSA is 29.53°. Measured SWA is 52.2°. Shell whorls flattened to very lightly convex in shape with distinct but very shallowly impressed sutures. Basal portion of shell is angular in shape, with an ovately shaped aperture. Parietal lip is thin and not reflexed, basal lip is strong and not reflexed. Shell likely has an umbilicus but it is covered.

“Hydrobia” subconica (Meek, 1876)

Plate V, Figure 29

Original Description.

> Shell of medium size, conoid-subovate; volutions about five, slightly convex, or almost flattened to the slope of the spire, last one rather large, and prominent or subangular around the middle, and somewhat produced below; suture not strongly impressed; aperture less than the length of the spire, rhombicoval, angular above, and subangular and a little effuse below; umbilical region excavated and provided with a small perforation; surface smooth. Length, 0.25 inch [6.35 mm]; breadth, 0.16 inch [4.06 mm]; length of aperture, 0.12 inch [3.04 mm], breadth of same, 0.08 inch [2.03 mm]; slopes of spire nearly straight, with a divergence from the apex of about 40° (Meek, 1876, p. 573).

Annotated Description. Shell is dextral, small (~6 mm in height), ovately conic in shape. Number of measured whorls is 4.14. Spire is elevated, comprising ~33% of shell. Measured MSA of 56°. Measured SWA of 20°. Shell whorls lightly convex with distinct, impressed sutures. Aperture is incomplete or in rough shape in type specimens.

Family Physidae

Genus *Aplexa* Flemming, 1820

Ecology. Burch (1989) found *Aplexa* in intermittent pools and streams. Baker (1928) found *Aplexa* in intermittent streams and stagnant pools. In Wisconsin, *Aplexa* is common in woodland pools that become dry in summer, and occasionally in small clean brooks in mud (Baker, 1928).

Aplexa atavus (White, 1877)

Plate V, Figure 20

Original Description.

> Shell large, much elongated; volutions about seven, increasing gradually in size; moderately convex; suture distinct but not deep; callus of the inner lip thin or absent; surface smooth, or marked only by very faint and very fine lines of growth. Some of the specimens have the appearance of having been naturally truncated or abruptly terminated at the apex, but it is more probable that this condition is the result of accident or erosion. Length, 50 millimeters, or more if the apex of the example measured be restored; diameter of body volution, 26 millimeters; length of aperture, 24 millimeters; full length of the spire beyond the aperture about equal to that of the aperture (White, 1877, p. 86).

Annotated Description. Shell is sinistral, large (48 mm in height) and narrowly elongate conic in shape. Number of measured whorls is 5.47. Spire is very elevated, comprising ~55% of the shell. Measured MSA of 37˚, measured SWA of 43˚. Shell whorls are lightly convex; sutures are not very distinct and shallow. Parietal lip is weak and not reflexed, but the rest of the aperture is missing in type specimens.

Genus *Physa* Daparnaud, 1801

Ecology. *Physa* live in shallow water, from a few inches to several feet [tens of millimeters to a meter], and are recorded from the bottom of deep lakes (Dawson, 1911). *Physa* can tolerate perennial and intermittent waters (Burch, 1989). Gangopadhyay et al. (2012) stated *Physa* tolerate permanent to temporary ditches, glacial lakes, wide range of water quality, and favor slow moving water.

Physa canadensis tenuis Russell, 1926

Plate V, Figure 21

Original Description.

> Shell medium to large; subovate in outline. Spire variable; volutions six or seven, last one large, longer than the spire and slightly shouldered; suture distinct. Aperture narrowly subovate to semi-ovate, acutely angular above, subangular or rounded below; outer lips thin and simple; inner lip with broad callus. Columella folded at the base. Surface marks with faint lines of growth. Length of adult shells, 14 mm to 53 mm (Russell, 1926, p. 216).

Annotated Description. Shell is sinistral, large (35.8 mm in height) and elongate conic to physaform in shape. Number of measured whorls is five. Spire is very elevated, comprising ~20% of the shell. Measured SWA is 36.7˚. Measured MSA is 36.7˚. Shell whorls flattened on the spire while the body whorl is convex in shape. Sutures are distinct but not very impressed. Umbilicus is absent or closed, and the aperture is narrowly ovate.

Physa copei White, 1877

Plate V, Figure 22

Original Description.

> Shell large, elongate subelliptical; volutions about four; body volution large and moderately inflated; spire short, less than one-third the entire length of the shell; suture distinct but not deep; aperture elongate subovate in outline; callus of the inner lip moderately thick; surface marked only by the ordinary faint lines of growth common to the genus. Length, 50 millimeters; diameter of body volution, 25 millimeters. This fine *Physa* is the largest species known to me except *P. pleuromatis* White, from the Wahsatch Group of Colorado, Wyoming, and Utah, some unusually large examples of which occur in the valley of White River, Northwestern Colorado (White, 1877, p. 602).

Annotated Description. Shell is sinistral, large (52.9 mm in height) and globose in shape. Number of measured whorls is 3.85. Spire is not very elevated to depressed, comprising ~4% of total shell height. Measured MSA is 46.2˚. Measured SWA is 46.4˚. Shell whorls are moderately convex and sutures are distinct and slightly impressed. Aperture measurements based on a reconstructed aperture on type specimen.

Physa subelongata (Meek and Hayden, 1856)

Plate V, Figure 23

Original Description.

> Shell elongate ovate; spire elevated, acute at the apex; volutions about six and a half, nearly flat; suture oblique, linear, scarcely distinct; surface faintly marked with lines of growth; aperture unknown; columella twisted into a kind of fold below the impressed umbilical region. Length 1.16 inches (29.46 mm); breadth .53 inch (13.46 mm); length of aperture about .57 inch

> (14.48 mm); apical angle very convex, divergence 49° (Meek and Hayden, 1856, p.120).

Annotated Description. Shell sinistral, medium to large (28 mm in height) and elongate conic in shape. Number of measured whorls 6.76. Spire is elevated, comprising 25% of shell height. Measured MSA is 40.66˚. Measured SWA is 52.68˚. Shell whorls flattened, with very shallow sutures. The type specimens are missing apertures but partial preservation implies an ovate aperture.

Family Pleuroceridae

Genus Lioplacodes Meek and Hayden

Ecology. Minton and Hayes (2008) suggested Pleurocerids prefer lotic, environments like shallow streams.

Lioplacodes gracilenta **(**Meek, 1876)

Plate VI, Figures 36a, b

Original Description.

> Shell small, slender, elongate-conoidal; volutions about seven, increasing gradually in size, convex but not rounded, last one a little produced below, but not proportionally much enlarged, and without a well-defined mesial angle; suture rather deeply impressed; surface very nearly smooth, or only showing under a magnifier very faint lines of growth, which are moderately sigmoid on the body-volution; aperture narrow-subovate, being somewhat obtusely angular above, and narrowly rounded and apparently a little effuse or sinuous below. Length, about 0.65 inch [16.51 mm]; breadth, 0.24 inch [9.1 mm]; slopes of spire nearly straight, with a divergence of about 25° (Meek, 1876, p. 633).

Annotated Description. Shell dextral, medium (18.42 mm in height) and conic in shape. Number of measured whorls is 6.5. Spire is very elevated, comprising 57% of shell height. Measured SWA is 25.03˚. Shell whorls convex in shape. Sutures impressed. Aperture is ovate in shape, with basal periphery rounded. Basal lip is weak and reflexed.

Lioplacodes invenusta **(**Meek and Hayden, 1857)

Plate VI, Figure 37

Original Description.

> Shell conical ovate; spire moderately elevated; volutions about seven, very slightly convex, increasing rather slowly from the apex; suture linear, not much impressed; surface marked by obscure lines of growth crossed by fine irregular rather indistinct revolving lines, a few of which, just below the suture, are larger than the others; aperture ovate; outer lip faintly sinuate above, rather prominent below the middle inner lip reflexed upon the imperforate columella, at the base of which it is broadly sinuous. Length .90 inch [22.86 mm]; breadth .37 inch [9.4 mm]; apical angle regular or a little convex, divergence 32° (Meek and Hayden, 1857, p. 137).

Annotated Description. Shell is dextral, medium (~20 mm in height) and ovately conic in shape. Number of measured whorls is 5.07. Spire is elevated, comprising 45% of the shell. Measured MSA is 35.13˚. Measured SWA is 31.5˚. Shell whorls are convex in nature. Sutures are distinct and impressed. Umbilicus is covered. Aperture is ovate in shape. Parietal lip is weak and not reflexed. Base of the aperture is rounded in shape.

Lioplacodes judithensis **(**Stanton, 1904)

Plate VI, Figure 40

Original Description.

> Shell of moderate size, stout, consisting of seven or eight very convex whorls; aperture very slightly produced below; surface marked by narrow, sharply elevated revolving lines, of which four to six

> are visible on the spire, separated by broader, flat bands which bear numerous minute revolving striae, and crossed by very fine growth lines. Height of an average specimen, 22 mm; breadth, 13 mm (Stanton and Hatcher, 1905, p. 117).

Annotated Description. Shell is dextral, medium (18 mm in height) and conic in shape. Number of measured whorls is six. Spire is elevated, comprising 50% of the shell. Measured SWA is 39.1˚. Shell whorls are rounded in nature. Sutures are deep and distinct. Roundness of whorls creates shouldering. Shell shows 4 to 5 revolving striae with medium strength. These striae appear on body and spire whorls. Type specimen does not preserve an aperture.

Lioplacodes praecursa Dyer, 1930

Plate VI, Figure 39

Original Description.

> Shell of moderate size, conical in outline; the volutions, which number five or six in those specimens having the apex preserved, flat-sided; body whorl slightly angulated at the base; surface marked by fine lines of growth, which in a few specimens are crossed by obscure revolving striae, suture very slightly impressed; aperture narrow, ovate; apparently imperforate. This species is distinguished from *C[ampeloma] vetula tenuis* by the flatness of the whorls, and, in consequence, the conical outline of the shell. It is quite similar to *C[ampeloma] producta*, but differs in the flatness of the whorls, there being no hint of a revolving ridge as in that species. *C[ampeloma] praecursa* is the forerunner of *C. producta* and allied species so common in the post-Bearpaw formations, just as *C. vetula* is the forerunner of *C[ampeloma] multilineata*. It has been found in both the Pale beds and Foremost members of the Belly River formation, but is more abundant in the lower member. Dimensions of Type. Length (one whorl missing), 18 mm.; breadth, 10 mm.; apical angle, 35 degrees (Dyer, 1930, p. 11).

Annotated Description. Shell is dextral, medium in size (20.25 mm in height) and is elongate conic in shape. Number of measured whorls is 4.5. Spire is elevated. Measured SWA is 25.55°. Measured MSA is 38.24°. Shell whorls are convex in shape. Sutures impressed. Umbilicus is open. Shape of the aperture is round with a strong but not reflexed basal lip.

Lioplacodes subtortuosa **(**Meek and Hayden, 1857)

Plate VI, Figure 38

Original Description.

> Shell conical screw-shaped; spire not much elevated; volutions about five, very convex, distinctly angular round the middle, increasing rather rapidly from the apex; suture strongly defined, in consequence of the prominence of the angular whorls; surface and aperture unknown. Length .29 inch [7.37 mm]; breadth .21 inch [5.33 mm] ; apical angle regular, divergence 47° (Meek and Hayden, 1857, p. 319).

Annotated Description. Shell is dextral, medium (~15 mm in height) and conical in shape. Number of measured whorls is 4.74. Spire is elevated, comprising 25% of the shell. Measured MSA is 58˚. Measured SWA is 47.31˚. Shell whorls are convex with a distinct revolving keel on whorl periphery. Shell sutures strongly impressed. Umbilicus closed. Aperture is ovate. Parietal and basal lips are strong and not reflexed.

Family Thiaridae

Genus *Melanoides* Olivier, 1804

Ecology. Populations also seem to tolerate, possibly even thrive in, somewhat elevated salinities (Roessler et al., 1977). Giovanelli (2005) claimed that some modern species of *Melanoides* prefer fast moving water such as river and streams.

Melanoides convexa **(**Meek and Hayden, 1856)

Plate V, Figure 24

Original Description.

> Shell rather large, much elongated, sub-cylindrical or terete; volutions (about ten?) flat, closely wound, and increasing very gradually from the apex; surface ornamented by fine lines of growth, crossed by distinct, regular, thread-like, revolving: lines, and extremely fine, nearly obsolete revolving striae; suture generally indistinct; aperture apparently ovate; lip thin, having a broad very shallow sinus below the suture, and another near the base of the columella. Length about 1.60 inches [40.64 mm]; breadth .48 inch [12.19 mm]; length of aperture .45 inch [11.43 mm]; apical angle convex, divergence 21°. Our best specimen of this interesting species consists of seven volutions, and appears to have lost two or three others from the apex; the aperture is also distorted. The larger revolving lines, about seven of which may be counted on the second volution, are quite distinct, and near one-third as wide as the spaces between, while the liner revolving striae are closely crowded, and so small as to be only seen by the aid of a good lens. The divergence of the apical angle, below the middle of an adult shell, is no more than 13°, while above, (and in young shells,) it is as much as 28° to 30° (Meek and Hayden, 1856, p. 125).

Annotated Description. Shell is dextral, large (39.54 mm in height) and is narrowly conic in shape. Number of measured whorls is 7.59. Spire is very elevated, comprising 67% of the shell. Measure MSA is 22.03˚. Measured SWA is 17.62˚. Whorls are flattened and barely convex. Sutures are distinct but shallow. Shell shows about seven very fine revolving striae. Aperture is ovate in shape. Parietal lip weak and not reflexed

Melanoides convexa impressa **(**Meek and Hayden, 1857)

Plate V, Figure 25

Original Description.

> From the same locality position as a *Melanoides convex*, we find amongst some of the late collection specimens presenting

> differences from that shell, which we suspect may be of specific importance; we are unwilling, however, felt more individuals for comparison, to run the risk of multiplying synonyms by attempting to characterize it as a distinct species. It is a more slender shell than *M. convexa*, the lower of volutons a more rounded, and the suture much more distinctly impressed, especially between the lower worlds. For the present we will designate this form as *Melanoides convexa var. impressa*, and in case further comparisons prove it to be a distinct species, it may be designated by the latter name (Meek and Hayden, 1857, p. 463).

Annotated Description. Shell is dextral, large (33.01 mm in height) and elongate conic in shape. Number of measured whorls is 5.97. Spire is very elevated, comprising ~60% of total height. Measured MSA is 26.5˚. Measured SWA is 20.4˚. Whorls lightly convex, sutures are distinct and impressed. Shell shows fine, revolving striae. Shell umbilicus covered. Much of the aperture is missing.

Melanoides? omitta **(**Meek and Hayden, 1857)

Plate V, Figure 26

Original Description.

> Shell small, very slender; spire elongate conical, acute at the apex; volutions about seven, flattened, or very slightly convex, increasing very gradually from the apex; suture linear, not deeply impressed; surface and aperture unknown. Length .42 inch [10.67 mm]; breadth .12 [3.05 mm]; apical angle regular, divergence 23°. Although we have seen neither the aperture nor surface markings of this little shell, we have ventured to characterize it, believing its slender form alone will serve to distinguish it from any of the other species with which it is associated (Meek and Hayden, 1857, p. 220).

Annotated Description. Shell is dextral, small (6 mm to 7 mm in height) and elongate conic in shape. Number of measured whorls is 4.92. Spire is very elevated, comprising ~50% of the height. Measured MSA is 27.08˚. Measured SWA is 18.4˚. Shell whorls are flattened. Sutures lightly impressed. Shell umbilicus covered. Aperture is ovate in shape. Basal periphery is angular. Parietal lip is weak and almost absent in the type specimen.

Melanoides sublaevis **(**Meek and Hayden, 1857)

Plate V, Figure 27

Original Description.

> Shell elongate conical; spire elevated (acute at the apex?); volutions (about seven?) very depressed convex; suture rather distinctly defined; surface apparently smooth, but when examined with a lens is seen to be marked by fine obscure lines of growth, crossed by extremely fine, nearly obsolete revolving striae; aperture ovate, angular above; columella and outer lip nearly equally arcuate; pillar faintly sinuous below. Length about 1.04 inch [26.42 mm]; breadth .38 inch [9.65 mm]; apical angle slightly concave, divergence 24° (Meek and Hayden, 1857, p. 136).

Annotated Description. Shell dextral, medium (23 mm in height) and elongate conical. Number of measured whorls is 5.4. Spire is elevated, comprising 45% of the shell. Measured MSA is 30.61˚. Measured SWA is 18.83˚. Shell whorls convex. Sutures are impressed. Shell shows fine revolving striae. Aperture is ovate. Umbilicus is covered. Parietal and basal lips are weak and not reflexed.

Family Vitrinidae

Genus *Vitrina* Müller, 1774

Ecology. Known in New Mexico from areas with low vegetation, damp meadows and along streams (Metcalf and Smartt, 1997). Araujo (2013) stated that *Vitrina* prefer meadows, grasslands, and forested areas.

Vitrina obliqua Meek and Hayden, 1857

Plate V, Figures 28a, b

Original Description.

> Shell obliquely oval; spire much depressed; volutions four to four and a half, first two or three increasing rather slowly in size, last one ventricose and rapidly enlarging, prominent below; suture distinct; aperture circular; surface unknown. Greatest transverse diameter .64 inch [16.26 mm]; height .50 [12.7 mm]; diameter of aperture .37 inch [9.4 mm] (Meek and Hayden, 1857, p. 134).

Annotated Description. Shell dextral, small to medium (7 mm to 13 mm in height) and ovately conic in shape. Number of measured whorls 3.74. Spire is depressed, comprising 25% of shell height. Measured SWA is 113˚. Shape of the shell is rounded with distinct, impressed sutures. Type specimens lack shell material and complete apertures.

Family Viviparidae

Genus *Campeloma* Rafinesque, 1819

Ecology. *Campeloma* is common in quiet waters with soft substrates containing some organic matter (Clarke, 1973). Burch (1989) found some species burrowing into sand or mud in rivers or lakes. Baker (1928) found *Campeloma* species in sandy-mud bottoms bordering rivers and lakes, in shallow waters.

Campeloma vetulum **(**Meek and Hayden, 1856)

Plate VI, Figure 34

Original Description.

> Shell conical-ovate, not very thick; spire relatively small, moderately elevated; volutions about five and a half, convex, narrow, increasing gradually from the apex, last one large and ventricose; surface marked with fine lines of growth, which are crossed by obscure revolving lines; suture strongly impressed, very slightly oblique; aperture narrow ovate; umbilical perforation closed or very small. Length about .81 inch [20.57 mm]; breadth

> .60 inch [15.24 mm]; length of aperture .40 inch [10.16 mm]; breadth of do. .24 inch [6.1 mm]; apical angle nearly regular, divergence 60° (Meek and Hayden, 1856, p. 121).

Annotated Description. Shell is dextral, medium (23.88 mm in height) and conic to ovately conic in shape. Number of measured whorls is 5.34. Spire is elevated, comprising 25% of the shell. Measured SWA is 61˚. Measured MSA is 57.79˚ Shell whorls are convex. Sutures are impressed. Umbilicus is covered. Aperture is ovate in shape. Basal and parietal lips are strong, not reflexed.

Campeloma vetulum pegmate Russell, 1934

Plate VI, Figure 35

Original Description.

> Shell as in *C. vetulum*, but with a narrow, distinct shelf along the posterior (apical) border of the whorls; body whorl relatively less ventricose. Length of holotype (first whorl missing), 20.1 mm; width, 11.9 mm; length of aperture, 9.7 mm (Russell, 1934, p. 131).

Annotated Description. Shell is dextral, medium (19 mm in height) and ovately conic in shape. Number of measured whorls is 3.96. Spire is elevated, comprising 20% of the shell. Measured MSA is 55.93˚. Measured SWA is 46.96˚. Shell whorls are convex. Sutures are impressed and distinct. The shell has a covered umbilicus. Aperture is ovate. Parietal and basal lips are strong and not reflexed.

Genus Viviparus Monfort, 1810

Ecology. *Viviparus* prefers floodplain fluvial channels (Hanley, 1969), shallow fluvio-lacustrine environments (La Rocque, 1960), and quiet ponds and bays (Burch, 1989). Baker (1928) found *Viviparus* in shallow rivers and lakes on mud bottoms.

Viviparus conradi **(**Meek and Hayden, 1856)

Plate VI, Figure 31

Original Description.

> Shell elongate-trochiform, thick; spire rather elevated, acute at the apex; volutions apparently about six, flat, last one more or less angular below the middle, and obliquely extended below; surface marked with fine lines of growth, crossed by delicate, nearly obsolete, revolving lines; suture linear; aperture subcircular, or broad ovate, obtusely angular above, (broadly rounded below?); columella profoundly depressed in the umbilical region; umbilicus none. Length about 1 inch [25.4 mm]; breadth .70 inch [17.78 mm]; length of aperture .44 inch [11.18 mm]; apical angle slightly convex, divergence 54° (Meek and Hayden, 1857, p. 579).

Annotated Description. Shell is dextral, medium (19 mm in height) and broadly conic in shape. Number of measured whorls is four. Spire is elevated. Measured MSA is 54°. Shell whorls are flattened. Basal periphery is rounded. Sutures are shallow. Aperture is round. Parietal lip is weak and not reflexed. Umbilicus is absent.

Viviparus montanaensis (Meek, 1876)

Plate VI, Figures 32a, b

Original Description.

> Shell attaining a rather large size, depressed-subglobose; volutions three, rather rapidly increasing in size, particularly in breadth; compressed-convex, both above and below; periphery in young and medium sized specimens angular, but becoming narrowly rounded in the adult; suture deep; umbilicus small; aperture about as wide as high in young and medium-sized specimens, angular on the outer side, but becoming more rounded in large examples; surface unknown. Height of largest specimen seen, 0.30 inch [7.62 mm]; greatest breadth of same, 0.40 inch [10.16 mm] (Meek, 1876, p. 591).

Annotated Description. Shell is dextral, small (4 mm to 5 mm in height) and depressed in shape. Number of measured whorls is 3.1. Spire is depressed, comprising 20% of total height. Measured SWA is 130˚. Shell whorls are rounded with deep sutures. Apertures not preserved on type specimens.

Viviparus nidaga Dyer, 1930

Plate VI, Figure 33

Original Description.

> Some of the forms which Meek regarded as *V[iviparus] conradi* depart rather widely from the typical form of the species. They are larger, more elongate, and have more rounded whorls. It is possible that they are simply specimens more advanced in size or age as Meek suggests, but they approach *V[iviparus] nidaga*, a new species from the Belly River formation, rather closely. In Alberta specimens have been found which definitely link the two species. The more typical form of *V. conradi* is represented by Meek's figures 15a and l5b, and the divergent form by figures 15c and 15d. *V. conradi* is rare in the Pale beds, but more common in the Foremost member of the Belly River formation. *Viviparus nidaga* differs *from V conradi*, the only species from the Belly River formation for which it might be mistaken, in the greater convexity of the whorls, in the absence of the angle at the base of the body whorl, and in the more elongate shape of the shell. The spiral whorls of the new species, however, are angular at the base. Certain species are clearly intermediate between *V. conradi* and *V. nidaga*, leaving no doubt of the close relationship of the two species. *V. nidaga* is close to *V[iviparus] leai* which occurs in several post-Bearpaw formations, differing chiefly in being larger and more slender in shape and in having more angular spiral whorls. It is rare in the Pale beds and in the Foremost member of the Belly River formation. The specific name means "prairie chicken" in Sarcee Indian. Dimensions of Type. Length, 27 mm.; breadth, 22 mm.; apical angle, 60 degrees (Dyer, 1930, p. 9).

Annotated Description. Shell is dextral, large (34.16 mm in height) and broadly conic in shape. Number of measured whorls is 4.32. Spire is elevated, comprising 30% of total shell. Measured SWA is 63.05˚. Measured MSA is 54˚. Shell whorls are flattened with the last whorl slightly convex. Sutures are impressed. Umbilicus is absent or closed. Aperture is circular in shape, and basal periphery is rounded.

Class Bivalvia

Family Corbulidae

Genus *Corbula* Bruguière, 1797

Ecology. Anderson et al. (2010) suggested that a Paleocene species previously assigned to *Corbula* (*Bicorbula mactriformis*) is found in freshwater deposits. The authors reassigned this taxon to the genus *Pachydon* with confirmation by trait analysis. Similar treatment may be suggested for some *Corbula* species in the Judith River Formation, as they occur in association with freshwater taxa in freshwater depositional environments.

Corbula subtrigonalis Meek and Hayden, 1856

Plate IV, Figure 16

Original Description.

> Left valve subtrigonal, very convex, obliquely truncate from the beaks to the extremities, the two slopes diverging at an angle of 95°; basal margin rounding up abruptly in front, and converging towards the posterior slope at an angle of about 48; beaks elevated, located in advance of the middle; surface marked by faint lines of growth, and having below the middle three or four concentric wrinkles, which become stronger towards the extremities. The right valve is much more compressed, and without concentric folds. Length .74 inch [18.77 mm]; breadth .25 inch [6.35 mm]; height .55 inch [13.97 mm] (Meek and Hayden, 1856, p.116).

Annotated Description. Shell is medium in size (23.11 mm in length), and triangular in shape. Dorsal margin has an abrupt change in curvature. Ventral margin is broadly convex. Umbo is narrow and does not contain sculpture. Beak is somewhat raised from the dorsal margin and is positioned anteriorly to the middle of the dorsum. Shell lacks pre and post umbonal sculpture. Growth lines vary in prominence. Posterior disc slopes abruptly, to near vertically. Lunule and escutcheon are narrow and short.

Corbula undifera Meek, 1873

Plate IV, Figure 15

Original Description.

> Shell of moderate size, trigonal-subovate, rather convex, the inequality of the valves not being very strongly marked, though always obvious; beaks moderately prominent, (that of the right valve being only a little more elevated than the other,) located in advance of the middle, contiguous, and in curved, with a scarcely perceptible forward inclination; posterior extremity subangular at the connection of its margin with the base; posterior dorsal slope more or less convex in outline; anterior margin rather short and rounded; base semi-ovate in outline, being most prominent anteriorly, and somewhat straightened behind; left valve about one-fourth less convex than the other, with posterior umbonal slope distinctly angular from the beak to the posterior basal extremity. right valve with posterior umbonal slope less strongly angulated; surface of both valves ornamented with concentric ridges, generally small and regular on the umbonal region, but often swelling out into a few very prominent, angular folds with rounded depressions, marked by distinct lines of growth, and some small ridges between, on the lower half of the valves; all the ridges and folds generally becoming obsolete behind the angular, posterior, umbonal slopes, but continued forward to the front. Length of a well-developed specimen, 0.70 inch; height to top of umbo of left valve, 0.50 [12.7 mm]; height to top of same of right valve, 0.58 inch [14.73 mm]; convexity of the two valves united, 0.41 inch [10.41 mm] (Meek, 1873, p. 513).

Annotated Description. Shell is medium (30.39 mm in length) and trapezoidal to triangular in shape. Dorsal margin has a distinct curvature change. Ventral margin is broadly convex. Posterior margin has an abrupt curvature change. Umbo is narrow, with incurved beaks. Umbo is raised prominently on the dorsal margin. Beaks are positioned centrally on the dorsum leaning slightly anteriorly. Shell shows varying growth-lines that form of ridges covering the shell. Lunule and escutcheon are narrow and short.

Family Cyrenidae

Genus *Corbicula* Megerle von Mühlfeld, 1811

Ecology. Sousa et al. (2008) stated that *Corbicula* could be found in both fresh and saline waters, in addition to fast and slow-moving waters.

Corbicula occidentalis (Meek and Hayden, 1856)

Plate IV, Figure 14

Original Description.

> Shell sub-triangular, very thick, rather ventricose; anterior end and base rounded, posterior end sloping abruptly from the beaks, and ventrically subtruncate at the extremity; beaks located a little in advance of the middle, and elevated, pointed, incurved, and approximate; surface marked with strong lines of growth. Length 1 inch [25.4 mm]; breadth .71 inch [18.03 mm]; height 1 inch [25.4 mm] (Meek and Hayden, 1856, p. 116).

Annotated Description. Shell medium in size (26.72 mm in length), and round to subcircular in shape. Dorsal margin is relatively straight. Ventral margin is convex in shape. Umbo is narrow in shape and lacks sculpture. Beaks are raised above the dorsal margin, are positioned in the center of the dorsum and pointed anteriorly. Shell lacks pre and post-umbonal sculpture. Growth lines are stronger near beaks. Lunule and escutcheon are both narrow and short.

Corbicula cytheriformis (Meek and Hayden, 1860)

Plate IV, Figure 13

Original Description.

> Shell broad trigonal ovate, varying to subcircular, rather thick and strong; extremities more or less rounded; base semiovate, usually more prominent before than behind the middle; dorsal outline sloping from the beaks, the anterior slope being more abrupt than the other, and slightly concave, while the posterior is convex; beaks rather elevated, moderately gibbous, located in advance of the middle; surface marked by fine lines of growth, which sometimes show a very slight tendency to gather into small irregular concentric wrinkles (Meek and Hayden, 1860, p. 176).

Annotated Description. Shell is medium in length (24.4 mm) and subcircular to round in shape. Umbo is narrow, lacks sculpture, and is somewhat elevated relative to dorsal margin. Beaks are placed anteriorly to the middle of the dorsum. Shell lacks sculpture on the disk. Disk slope has an abrupt curvature no associated with a ridge. A ligament is preserved. Lunule and escutcheon are short and narrow in shape.

Family Sphaeriidae

Genus: *Sphaerium* Scopoli, 1777

Ecology. *Sphaerium* is preferential to shallow water of temporary ponds and is able to survive drying of such ponds in late summer. Other species show little preference with respect to kind of bottom, depth of water, or nature of stream or lake. Fossil species are of no special value as ecological indicators except to indicate clean, fresh water without undue amounts of chemical or organic pollution (La Rocque, 1960). Baker (1921) stated that *Sphaerium* is found in typically small pools or slow moving streams.

Sphaerium planum Meek and Hayden, 1860

Plate IV, Figure 17

Original Description.

> Shell rather small, broad oval or subcircular. much compressed; extremities more or less regularly rounded, the posterior margin being sometimes faintly subtruncate; base semi-oval in outline ; cardinal margin rounding gradually from near the middle; beaks very small, compressed, and scarcely extending beyond the hinge margin, nearly central; surface marked by fine irregular, obscure, concentric striae. Length, 0.38 inch [9.65 mm]; height, 0.32 inch [8.13 mm]; convexity 0.08 inch [2.03 mm] (Meek and Hayden, 1860, p. 175).

Annotated Description. Shell is small (10.14 mm in length), and almost circular in shape. Ventral and dorsal margins are convex in shape. Umbo is very narrow and lacks sculpture. Disc is little incurved and quite flat. Disc lacks sculpture. Beaks placed centrally on the dorsum, and are point slightly anteriorly. Growth lines vary in prominence, thicker lines trending towards margins.

Sphaerium recticardinale Meek and Hayden, 1860

Plate IV, Figure 18

Original Description.

> Shell of medium size, transversely subelliptical, rather compressed, very thin; anterior side rounded; base forming a regular semielliptic curve; posterior extremity obliquely subtruncate above, and rather narrowly rounded below; cardinal margin long and straight; beaks very small, compressed, and projecting but slightly above the hinge, located nearly half way between the middle and the anterior end; surface marked by moderately distinct, irregular lines of growth. Length, 0.55 inch [13.97 mm]; height, 0.33 inch [8.39 mm]; breadth, 0.24 inch [6.1 mm] (Meek and Hayden, 1860, p. 176).

Annotated Description. Shell is small (14.7 mm in length), and somewhat rectangular in shape. Dorsal and ventral margins are broadly convex in shape, though a marked curvature change is seen on some specimens on the ventral-posterior margin. Umbo is narrow and slightly raised above the disc. Shell lacks sculpture, both on the disc and umbo. A posterior ridge is pronounced on some specimens, leading from the umbo to the ventral-posterior margin. Beak is placed slightly anteriorly of the center of the dorsum and is pointing anteriorly.

Sphaerium subellipticum Meek and Hayden, 1856

Plate IV, Figure 19

Original Description.

> Shell small, elliptical-ovate, somewhat ventricose, thin and fragile; posterior end narrower than the anterior, both narrowly rounded; base semi-elliptical or semi-ovate; cardinal border apparently rounding gradually to both extremities; beaks not much elevated, pointed, incurved, not oblique, located near the middle; surface indistinctly marked with lines of growth. Length 0.24 inch [6.1 mm]; height 0.14 inch [3.56 mm] (Meek and Hayden, 1856, p. 115).

Annotated Description. Shell is small (6.93 mm in length for a 95% complete shell) and ovate in shape. Shell is flat and not very convex. Ventral and dorsal margins are broadly convex in shape. Umbo is broad relative to the shell and lacks sculpture. Beaks are not prominent and are located centrally on the dorsum. Shell body also lacks sculpture.

Family Unionidae

Genus *Anodonta* Lamarck, 1799

Ecology. Boycott (1936) stated some species of *Anodonta* prefer firm, muddy bottoms, and live in slow rivers, canals, large draining ditches, lowland lakes, reservoirs and large ponds. Taylor (1983) found modern *Anodonta* from California in perennial creeks, rivers, and lakes.

Anodonta propatoris White, 1877

Plate II, Figure 5

Original Description.

> Shell elongate subelliptical in marginal outline; valves moderately and somewhat uniformly convex; beaks small, slightly elevated above the cardinal border; hinge-line long and straight; basal border broadly convex; front regularly rounded from the base up to the antero-dorsal border, which latter border is more abruptly rounded to the hinge-line; postero-dorsal border oblique and slightly convex; postero ventral border somewhat abruptly rounded from the postero-dorsal to the basal border; cardinal margin slightly thickened but entirely plain and characteristic of the genus *Anodonta*. Surface plain, or marked only by the usual lines and undulations of growth. Length of the largest example in the collection, 62 millimeters: height of the same from base to beaks, 30 millimeters; length of a partly grown example, 37 millimeters; height of the same, 20 millimeters (White, 1877, p. 607).

Annotated Description. Shell is long (64.08 mm in length), elongate to elliptical in shape. Dorsal margin is relatively straight. Ventral, posterior and anterior outlines are moderately convex. Umbo is broad, raised slightly above the hinge line, and lacks sculpture. Beaks are located anteriorly to the central margin of the shell but not on the terminal margin. Lunule is narrow and short. Escutcheon is narrow and long in shape. The type does not provide an internal view.

Genus *Lampsilis* Rafinesque, 1820

Ecology. La Rocque (1960) stated the genus had few definite ecologic preferences. Species have been collected in large and small lakes and rivers, in fast and slow-moving water, in shallow and deep water. Some living species of the genus are quite hardy as regards temperature. Haag (2012) suggested that *Lampsilis* preferred slow waters, near shore, with muddy bottoms.

Lampsilis consueta (Whiteaves, 1885)

Plate I, Figure 4

Original Description.

> Shell rather large, moderately convex, (the maximum thickness through the closed valves as compared with their height being about as three to five) transversely elongated, a little more than twice as long as high, very inequilateral, the anterior side being extremely short, and the posterior much produced; superior and interior borders very nearly parallel for the greater part of their length. Margins of both extremities evenly rounded in some specimens, but in others the posterior end is bluntly pointed just below the middle. Superior border descending obliquely, convexly and abruptly in front of the beaks, nearly straight and horizontal, but slightly convex behind them: ventral margin also nearly straight except at the immediate extremities, apparently never concavely arcuate near the centre; sides of the valves also never concave near the midlength below. Beaks very small, depressed, ill-defined and approximated, placed very near the anterior margin but not quite terminal. Surface marked with the usual concentric lines of growth. Hinge dentition unknown. Dimensions of the most perfect specimens collected: length, one hundred and fifteen millimetres, or a little more than four inches and a half: height of the same, fifty-one mm. In this individual, which is a little distorted and twisted to one side, the valves are partially open, so that the exact thickness through them is difficult to ascertain, but in another specimen which appears to belong to the same species and whose valves are closed, the maximum height is fifty millimeters, and the greatest thickness of both united is about thirty (Whiteaves, 1885, p. 59).

Annotated Description. Shell is long (88.04 mm for a complete specimen) and broadly ovate in shape. Dorsal, ventral posterior and anterior edges of the shell are convex in shape. Umbo is broad, lacks sculpture. Beaks placed centrally on the dorsum. Growth lines readily defined. Posterior ridge is abruptly shaped.

Genus *Plesielliptio* Russell, 1934

Ecology. La Rocque (1960) stated living species of the genus *Elliptio* show great tolerance of environment. They range from inhabiting creeks, medium and large rivers, and the Great Lakes. It is equally common on gravel, sand, and mud at depths of less than one foot to more than three feet. In themselves, fossil species of *Elliptio* are poor indicators of ecologic conditions. Haag (2012) suggested *Elliptio* prefers slow currents near banks of rivers.

Plesielliptio abbreviatus (Stanton, 1904)

Plate I, Figure 1

Original Description.

> This variety has the general aspect and sculpture of *U[nio]. priscus*, with the strong concentric wrinkles on the beaks and two elevated radiating lines on the posterior umbonal slope, but it differs in having the posterior end relatively much shorter and somewhat broader, and it is apparently somewhat more convex. The shell is rather thin and the hinge teeth are light. The specimens figured are from Milk River, about 5 miles south of Wild Horse Lake (Stanton, 1904, p. 108).

Annotated Description. Shell is long (57.39 mm in length for a shell 66-75% complete) and is ovate in shape. Dorsal, ventral, posterior and anterior margins are convex in shape. Umbo is broad, covered in Plesielliptio-like sculpture, with beaks moderately elevated on the hinge line. Posterior disc slope is very abrupt. Lunule is ovoid in shape and long, escutcheon is short and narrow. Left valve has two cardinal teeth, both with heavy mass and pyramidoid in shape. These teeth run parallel to the dorsal margin. No lateral teeth preserved. The shell also preserves one abductor muscle scar (anterior) of medium size that is round in shape.

Plesielliptio danae **(**Meek and Hayden 1857)

Plate II, Figure 6

Original Description.

> Shell elongate, arcuate, and oblique, contracting posteriorly; anterior end regularly rounded; base slightly arched, most contracted a little behind the middle; posterior end cuneate, rather narrowly rounded; dorsal margin sloping with a long convex curve from near the umbones towards the posterior end; beaks depressed, not very distinct from the dorsal edge, placed a little more than one-fourth the length of the shell from the anterior end; flanks concave from the umbonal region obliquely downwards to the most arcuate portion of the base; hinge moderately thick; cardinal teeth corrugated, strong, apparently double in the left valve, and single in the right; lateral teeth long and slender; surface (of specimens with the epidermis removed) marked by faint lines of growth, and very obscure radiating striae. Length 3.50 inches (88.9 mm); height 1.54 inches (39.98 mm); breadth about 1 inch (25.4 mm) (Meek and Hayden, 1857, p. 432).

Annotated Description. Shell is long (84.73 mm in length) and elongate in shape. Dorsal margin is broadly convex, while the ventral margin contains a concave kink near the center. Umbo is broad, and occasionally preserves sculpture. Beaks are located low on the dorsal margin and positioned anteriorly to the center of the dorsum. Growth lines are faint and of varying prominence. Posterior disc slope curvature is slightly noticeable but is not associated with a ridge. Lunule is short and narrow, escutcheon is narrow and long.

Plesielliptio deweyanus **(**Meek and Hayden, 1857)

Plate II, Figure 7

Original Description.

> Shell rather thick, oblique, narrow-ovate, approaching a narrow-elliptic form, most convex in the umbonal region, more compressed and cuneate posteriorly; extremities rounded, anterior end a little wider than the other; base broad, semi-ovate; dorsal margin nearly straight, and sloping gradually from near the beaks

> towards the posterior end; beaks small, not very distinct from the dorsal border, almost terminal in old shells, but in young individuals a little more removed from the buccal margin; surface (of specimens with the epidermis wanting) showing obscure lines of growth, crossed by very fine indistinct irregular radiating striae; ligament long; hinge much thickened at the anterior end of the valves, composed of two rough irregular cardinal teeth in the left valve, and one more prominent tooth in the right; lateral teeth long and slightly arched; dorsal cicatrix located nearly under the beaks, not very deep; anterior cicatrix distinct, and strongly corrugated; cavity of the beaks shallow. Length about 2.60 inches [66.04 mm]; height 1.33 inches [33.78 mm]; breadth about 1.18 inches [29.97 mm] (Meek and Hayden. 1857, p. 145).

Annotated Description. Shell is long (59.55 mm in length), and elongate to ovate in shape. Dorsal and ventral margins are broadly convex in shape. Umbo is broad and does not show sculpture. Beaks are low relative to dorsal margin and placed terminally on the anterior end of the dorsum. Dorsal margin shows a slight kink. Shell lacks pre and post umbonal sculpture. Disk shows a slightly convex curvature. Lunule is short and narrow, and escutcheon is narrow and long. Umbonal cavity is long, curved, and shallow. Hinge plate is relatively wide and slightly curved. Left valve cardinal teeth are heavy in mass, pyramidoid in shape, and complex in texture. Right valve cardinal tooth is moderately massed, pyramidoid in shape, and of a moderate height. Right valve lateral tooth is serrated, straight and short. Left valve preserves one muscle scar that is round, medium in size, and rough in texture. Right valve preserves a single muscle scar that is medium in size, and roughly textured.

Plesielliptio priscus **(**Meek and Hayden, 1856)

Plate II, Figure 8

Original Description.

> Shell ovate, rather compressed, very thin and fragile; anterior extremity short, rounded; posterior end narrower, contracting with

> a regular curve from above, and having at the extremity below a very obtusely rounded angle; cardinal border broadly arcuate; basal margin nearly straight behind the middle, rounding up in front; beaks very small, rising little above the hinge, located about one-sixth the entire length of the shell behind the front, and ornamented with small regular concentric wrinkles; surface of other portions of the shell smooth, or only marked with fine lines of growth. Length 2.78 inches [70.61 mm]; breadth unknown; height 1.63 inches [41.4 mm] (Meek and Hayden, 1856, p. 117).

Annotated Description. Shell is long (69.54 mm in length for a complete specimen) and ovate in shape. Ventral margin is nearly straight. Dorsal margin is broadly convex. Umbo is broad with slightly incurved beaks. Beaks are placed anteriorly to the middle dorsum and are not very prominent. Shell has *Plesielliptio*-type sculpture around the umbonal region and posterior of the umbo. Lunule and escutcheon are short and narrow.

Plesielliptio stantoni **(**White, 1905)

Plate III, Figure 10

Original Description.

> The specimen here figured under the name of *U[nio] stantoni*, in honor of Dr. T. W. Stanton, was formerly referred to *U[nio] danae* Meek and Hayden of the Judith River beds; but it proves to be different in specific features and to come from a much higher position in the Cretaceous series (White, 1905, p. 99).

Annotated Description. Shell is large (81.56 mm in length for a complete specimen) and elliptical to ovate in shape. Ventral and dorsal margins are both broadly convex in shape. Umbo is broad, with incurved beaks. Beaks positioned low and terminally anterior. Shell shows no sculpture (which could be due to preservation). Shell is almost vertical in posterior disc slope. Lunule is shot and narrow. Escutcheon is long and narrow.

Genus *Pleurobema* Rafinesque, 1819

Paleoecology. Hove and Neves (1994) stated species of *Pleurobema* were known from a variety of environments. *Pleurobema* prefer stagnant to fast moving waters, with silt and sand substrates.

Pleurobema cryptorhynchus (White, 1877)

Plate III, Figure 11

Original Description.

> Shell of medium size, ventricose, subelliptical in marginal outline; height a little greater forward of the mid-length than elsewhere; test moderately thick; dorsal margin nearly straight or slightly convex; basal margin broadly convex; posterior margin regularly rounded; front margin also regularly rounded from beneath the beaks to the ventral margin; beaks rather large, distinctly defined from the body of the shell, not elevated, but projected forward and turned strongly inward, placed near the anterior end of the shell, but not reaching quite so far forward as the anterior border, between which and the beak there is a distinct sulcation; cardinal teeth strong ; each valve having behind the cardinal teeth a moderately deep crypt or cavity of the beak; lateral teeth well developed, but thin and sharp. Surface marked only by the ordinary lines and laminations of growth. Length, 70 millimeters; greatest height from base to umbo, 45 millimeters (White, 1877, p. 372).

Annotated Description. Shell is long (52.67 mm in length), and narrowly ovate in shape. Dorsal margin is nearly straight while the ventral margin is broadly convex. Umbo is broad in shape, with incurved beaks, and lacks sculpture. Beaks are close to the dividing margin, and are placed between the middle of the dorsum and anterior end. Shell growth lines vary in prominence. Shell preserves a ligament. Lunule and escutcheon are narrow and short.

Genus *Ptychobranchus* Rafinesque, 1820

Ecology. Cummings (1992) found *Ptychobranchus* in medium to small rivers, relatively fast waters, and that it prefers sand and gravel substrates.

Ptychobranchus subspatulatus **(**Meek and Hayden, 1857)

Plate III, Figure 11

Original Description.

> Shell moderately thick, oblique, elongate-ovate, rather compressed, most convex at the anterior end, cuneate behind; buccal end wider than the other, abruptly rounded or subtruncate; posterior end narrowly rounded; base nearly straight or very slightly concave; dorsal margin sloping a little, with a long, convex curve from near the umbones, towards the posterior end; beaks small, not much elevated, located at the anterior end; surface (epidermis gone) showing faint lines of growth, crossed by fine irregular, radiating striae; hinge and interior unknown. Length 2.83 inches [71.88 mm]; height 1.34 inches [34.04 mm]; breadth .75 inch [19.05 mm] (Meek and Hayden, 1857, p. 146).

Annotated Description. Shell is long (71.5 mm in length), and ovate to elliptical in shape. Anterior margin is convex in shape, and posterior margin is more narrowly convex. Dorsal and ventral margins are broadly convex in shape. Ventral margin has a concave structure. Umbo is broad and shows well preserved radiating *Plesielliptio*-like sculpture. Umbo is placed terminally on the dorsum. Beaks are incurved, depressed and point anteriorly. Disc also shows *Plesielliptio*-like radial ridges. Growth lines are stronger near margins. No lunule or escutcheon present in type specimens. Umbo is long, curved, and deep. Hinge plate is narrow, slightly curved and moderately developed. Left valve cardinal teeth number two. Posterior and anterior teeth have a moderate mass, pyramidoid shape, and are very complex in structure. Lateral teeth are strong, relatively long, and straight. Left valve cardinal teeth are trianguloid in shape, moderately complex, and of a moderate mass. Lateral tooth is weak, of medium length, and straight. Left valve shows to muscle scars that are medium in size, shallow and with limited structure. Right valve shows two muscle scars that are moderately developed, smooth and of medium size. Pallial line is barely developed.

Genus *Quadrula* Rafinesque, 1820

Ecology. Watters et al. (2009) found *Quadrula* in North America in rivers in shallow water on coarse gravel. Water velocity in these areas was slow but not stagnant. Haag (2012) states that *Quadrula* prefers faster waters of main channels.

***Quadrula* primaevus (**White, 1877)

Plate I, Figure 3

Original Description.

> Shell of medium size, broadly subovate in marginal outline when adult, but proportionally narrower when young 5 valves moderately convex, each having a faint umbonal sinus or radiating flattened space, which ends at the basal margin a little behind the mid-length of the shell 5 this sinus or flattened space is bordered posteriorly by a broad undefined, umbonal ridge, or slight radiating prominence which ends at the postero-basal border; beaks situated nearly equidistant from the anterior and posterior ends, or a little nearer to the anterior, prominent by reason of the sloping away from it of both the antero and postero dorsal borders as well as the sides; from the beaks to the postero-basal portion of the shell the margin is broadly convex; postero-basal margin abruptly rounded to the base, the latter margin being gently convex, or sometimes a little straightened where it is met by the umbonal sinus or flattened space; front regularly rounded; both cardinal and lateral teeth well developed; the cardinal tooth of the left valve passing into a pit in the right valve which is situated directly under the beak. The posterior end of the lateral portion of the hinge has a peculiar

> modification of the usual method of articulation in *Unio*, as shown by fig. 35, plate 29. It also ends by a thickening of the substance of the hinge and a rounding of its end, instead of having the lateral teeth ending sharply as is usual in shells of the genus *Unio*. Surface marked by the ordinary lines and undulations of growth, and the postero-dorsal portion is also marked by irregular raised linear ridges that have a somewhat corrugated appearance, their direction being from the beak towards the posterior and posterobasal borders. Besides these markings exfoliated portions of the test show fine radiating lines. This shell may be readily distinguished by its broadly subovate outline and the peculiar irregular raised lines on the postero-dorsal surface. The peculiar character of the end of the lateral portion of the hinge which is seen in this shell is also to be observed in *U[nio] stewardi* White, from the Jurassic strata of Northern Utah, but the hinges of the fossil Uniones that have hitherto been found in the Mesozoic and Cenozoic rocks of Western North America do not otherwise show any differences from those which prevail among the living Uniones of North American rivers. Length of an adult example, 65 millimeters; height of the same from base to beaks, 49 millimeters (White, 1877, p. 599).

Annotated Description. Shell is medium in size (63.51 mm in length) and subcircular to circular in shape. Dorsal and ventral margins are convex in shape. Umbo is broad in shape and beaks are little incurved. Beaks and umbo lack sculpture and are depressed and positioned well anteriorly of the middle on the dorsum. Pre and post-umbonal sculpture absent. Growth lines of varying prominence. Lunule and escutcheon are narrow and short. Umbonal cavity of the shell is short and deep. Hinge plate is slightly curved, moderately developed, and narrow. Right valve has one cardinal tooth that is peg-like to conoid, complex and strong. Lateral tooth is smooth, narrow and weak in strength. The shell preserves two muscle scars that are medium in size, moderately developed and moderately divided. The shell also preserves a strong pallial line.

Quadrula supenawensis **(**Stanton, 1904)

Plate III, Figure 12

Original Description.

> Shell of medium size, obliquely subovate in outline, with relatively thick test and broad hinge plate; beaks very prominent, slightly incurved, very near the anterior end of the shell, and sculptured with distinct concentric wrinkles; the rest of the surface showing only ordinary lines of growth and very faint radiating striae, which probably are not visible except when the actual surface is slightly exfoliated; dorsal and basal margins forming very gentle regular curves; anterior margin slightly excavated above in front of the beak and broadly rounded below; posterior end somewhat narrowly rounded; shell very gently convex in the umbonal and median portions, but abruptly descending toward the front and dorsal margins; cardinal teeth large, very irregular in form, and strongly corrugated; posterior lateral well developed, elongate. Length of type, about 65 mm; height, about 55 mm; convexity of single valve, 22 mm (Stanton, 1904, p. 46).

Annotated Description. Shell is long (57.85 mm for a 75% complete shell) and is subcircular to ovate in shape. Dorsal and ventral margins are broadly convex in shape. Umbo is broad and prominent, positioned near terminally. Beaks lack sculpture (likely because of preservation). Pre- and post-umbonal sculpture absent. Growth lines are stratified, with stronger lines near the beaks. Umbonal cavity is deep. Hinge plate is wide and slightly curved. Left valve preserved two cardinal teeth. Posterior tooth is moderate in size, pyramidoid in shape and complex in structure. Anterior tooth is moderate in size, triangular in shape and complex in structure. Shell preserves two lateral teeth, which are long, strongly preserved and straight. Shell preserves a V-shaped socket in the left valve. Shell preserves one muscle scar, which is round in shape, moderately deep, and complex in structure.

Genus *Rhabdotophorus*

Ecology. Zieritz et al. (2012) stated that Unioni can be found in both lakes and streams, but prefer fast-moving water of riverine environments.

Rhabdotophorus senectus **(**White, 1877)

Plate III, Figure 9

Original Description.

> Shell elongate-subelliptical in marginal outline; convexity of the valves comparatively slight, and nearly uniform over the whole surface; test thin; both basal and dorsal margins broadly convex, or the former sometimes a little straightened; front regularly rounded; posterior margin also rounded, but sometimes more abruptly so than the front, beaks scarcely definable as such from the body of the shell, situated at about one fifth the length of the shell from the front; hinge well developed; cardinal teeth prominent, but somewhat thin; lateral teeth long and well formed, having between their anterior end and the cardinal teeth a considerable plain space. Above and behind a line drawn from the beaks to the postero-basal margin, that is, along the line of the umbonal ridge, when one is present, the surface is marked by very numerous small crenulated undulations, which increase in number both by implantation and, bifurcation with the increasing size of the shell; their general direction being backward, but along the dorsal portion of the valve they are flexed upward and end upon the dorsal margin. Below and in front of this line the surface is plain, being marked only by the ordinary lines of growth, except some fine radiating lines which appear in the substance of the shell when it has been exfoliated. Length, 80 millimeters; height, 40 millimeters (White, 1877, p. 195).

Annotated Description. Shell is long (82.59 mm in length), and elliptical to elongate in shape. Dorsal margin in broadly convex while the ventral margin is relatively straight. Umbo is broad and contains no sculpture. Beaks are placed terminally on the anterior portion of the shell. Growth lines vary in prominence. Post-umbonal part of the shell lacks sculpture, though this is likely due to preservation. Lunule is narrow and short. Escutcheon is narrow and long. Interior of the shell shows a narrow, slightly curved hinge plate. Lateral tooth on right valve is smooth, weak and short in length. Internal shell also presents a strong pallial line.

METHODS

This project required field work in the type area and elsewhere at historically important locations to understand the field context of species named from the Judith River Formation that have gone largely undocumented. Fossil collecting occurred over the course of two summers (2014, 2015) and a short trip in the fall of 2014 to add specimens from previous study locations of Dr. Joseph H. Hartman and crews and by crews of the University of California-Berkeley Museum of Paleontology (UCMP). A crew spent a week in the summer of 2014 to collect specimens in the type area of the Judith River Formation along Dog Creek and its tributaries ("Judith Badlands"). A University of North Dakota paleontology class field trip conducted in November 2014 to reinvestigate UCMP localities on Redding Farm. This trip allowed for the planning for a 2015 week-long trip to the Redding Farm in the summer of 2015. Don McCollor and Dr. Hartman and crew investigated 14 additional localities and sample sizes were increased. Specimen collection at each locality did not attempt to parse the shell assemblage contained in the thick and extensive well-lithified shell bed into discrete depositional events. Meter or more thick shell beds represent time-compressed depositional units composed of varying depositional conditions through time and thus contain, depending on circumstance, different fossil elements. Collecting shells vertically and laterally through the bed, and well-associated float at each locality, created a population sample of each shell bed. (Fig. 3). The crew only performed methods necessary to ensure safe transport because of time and maintaining shell quality.

Preference was given to collecting in situ specimens. Collecting float was limited to situations where producing beds could be identified with certainty, and were only collected if similar morphologies could be attained *in situ* at each locality. Such precautions minimize potential contamination from float from unseen or undocumented horizons, as the presence and absence of species in an assemblage or at a horizon were important aspects of the study. Specimens were collected with a bias toward more complete specimens. Occasionally, significantly incomplete specimens were collected because they showed easily identifiable traits for species diagnoses.

Figure 3. Photo of Locality L7200. Dotted line indicates shell horizon. Circles indicate collection sections. Jacob's Staff for scale (Photo by Robert Grahams, July 11, 2014).

A weeklong trip was taken to the National Museum of Natural History (NMNH, Smithsonian Institution) in August 2015 to photograph and document type and figured molluscan specimens from the Judith River Formation and stratigraphically and evolutionarily allied taxa. Meek, Hayden, White, and Stanton primarily collected specimens examined. Specimens were typically photographed in a set number of standard views (Fig. 2) to ensure accurate measurements (Table 1). Following Hartman (2015) and others, the apertural view in gastropods represents the aperture facing the camera lens, “film” plane or digital surface, with the apex pointing “up”. In apertural view, the coiling axis is parallel to the digital imaging surface for all measurements taken in this view. Height, width, spire angle measures and “apparent” aperture height and width measurements are taken in apertural view (Table 1). All views were photographed with a Nikon D7100 camera mounted to a stable copy stand. Each view was shot three times with varying exposure levels to optimize for the best lighting. All specimens were photographed with the same Starrett engraved millimeter scale. Photos were organized, selected, and subsequently used for the previously mentioned measurements.

Specimens collected were separated into morphotypes. Otherwise unnumbered specimens selected for study were given a Dr. Hartman S-number, resulting in a five-digit number which was recorded both in a database and on labels placed with the specimens.

With most specimens, the plane created by the snail’s aperture is not parallel to the film plane. Thus, consistent aperture height and width measurements were taken from photographs taken in a view where the aperture is parallel to film plane (aperture flush view). Aperture flush view allows for direct apertural measurements and a good view of the generating curve.

Depending on the handedness of the snail, dextral (right) or sinistral (left) was recorded. To obtain a view of the apertural plane and growth line pattern 90° to the apertural view, a right lateral view was shot if the specimen is dextral. If sinistral, a left lateral view was photographed. Shape of the growth lines, change in whorl history (descent of whorl in some snails), and retraction of the apertural plane was documented. An apical view was shot to accurately count a specimen's number of whorls. In most specimens, focal-plane stacking of images was done to acquire a specimen completely in focus. Lastly, a basal shot was taken to document last whorl sculpture, basal periphery, and any details of the umbilical region not otherwise captured in the apertural flush view (Figure 4).

Traditional views of mussel specimens were taken. These include external and internal views of left and right valves. If articulated (conjoined), both external valves were photographed for measurements, along with dorsal and ventral views, and, sometimes anterior and posterior views. Other views of sculpture were taken as deemed necessary. Internal views capture muscle scars, inflation of the valve, umbonal cavity, beak length, and shell dentition.

Many specimens have obstructed views, with valves filled or partially filled by unextractable matrix. Dorsal and ventral views permit measurement of valve (shell) width, strength of shell dentition, sculptural and others features, and valve shape. Posterior and anterior views were also shot to aid in the measurement of shell expansion and changes in curvature (angulation) of the disc. Dorsal oblique views permit better examination of umbo shape and sculpture (Table 1).

Table 1. Views used to photograph fossil mollusk traits. Views were taken to ensure entirety of shell was documented.

Shell Type	View
Snail	Apertural
	Apertural Flush
	Apical
	Basal
	Right Lateral
Clams	External shell
	Internal Shell
	Dorsal
	Ventral
	Posterior
	Anterior
	Dorsal Oblique

Software

Commercial software products were used to manipulate specimen photos, take measurements and perform the analysis. Adobe® Photoshop® was used to reorient specimen images into standard views and to prepare them for use in CorelDraw®. Prepared specimen images were imported into CorelDraw® for measurement, to make specimen plates and other diagrams. Helicon Focus© was used to composite multiple focal plane images. Many specimens were processed in this manner. Such images were opened in Photoshop® for subsequent editing.

CorelDraw® was used to measure distance and angle character traits. CorelDraw® image space was calibrated using the scale in the specimen photos. Microsoft Excel™ was used to record measurement data and trait characteristics, make graphs of data and trait characters. MacClade (Maddison and Maddison, 2005), a Macintosh® program used for organizing data into matrices, was used to import the collected trait data in PAUP* (Swofford, 2002), which is a program that uses parsimony to perform phylogenetic analysis.

Measurements

Measurements were made on United States National Museum Paleontology(USNM-PAL) and numbered primary and secondary continental molluscan types in the NMNH collections. Other specimens of value were selected to represent the morphology of various traits necessary to accurately diagnose species. The types of some species (e.g., *Lioplacodes subtortuosa*) are too poor to measure in a meaningful way. In cases where measurements were not useful, they have not been recorded here. In some cases, minor adjustments were made, such as suggested completion of a whorl or where previous researchers/preparers reconstructed missing shell permitted close measurement approximations.

Length measurements chosen for the mussel/sphaeriid specimens were fewer in number (Table 2). Length (RVL, LVL) and height (RVH, LVH) of right and left valves were taken when possible. These two measurements describe overall size of the shell, general shape, and whether the shell is elongate and narrow. Width of both valves (RVW, LVW) was measured to provide information on convexity of the valves. Beak length (RVBL, LVBL) or length from the beak to the anterior margin was measured to understand beak placement on the dorsal margin. For both valves, external and internal, anterior, posterior, dorsal, and ventral views were taken to ensure complete photographic coverage of the shell.

Species character traits chosen to represent shell morphology were based on criteria fundamental to paleontological study (Fig. 2). Because fossilization does not usually preserve soft body parts, many traits useful in modern mollusk taxonomy cannot be used. Character traits chosen for the gastropods were (Table 3): number of whorls, mean spire angle (MSA), maximum height (MHI), photograph measured height (PHI), photograph measured width (PWI), photograph body whorl height (PBH), photograph spire height from the second spire width (PSH1), photograph spire height from the first spire width (PSH2), photograph measured first spire width (PSW1), photograph measured second spire width (PSW2), aperture height (PAH), aperture width (PAW), spire width angle (SWA), apertural flush height (FAH), and apertural flush width (FAW). The number of whorls is an important character trait as it varies importantly from species to species relatively to shell height and width. Understanding the rates of whorl expansion and translation are only best determined on specimens preserving complete apexes. MSA and SWA both look at spire dimensions, MSA concentrating on the PSW1 width and SWA concentrating on the PSW2 width.

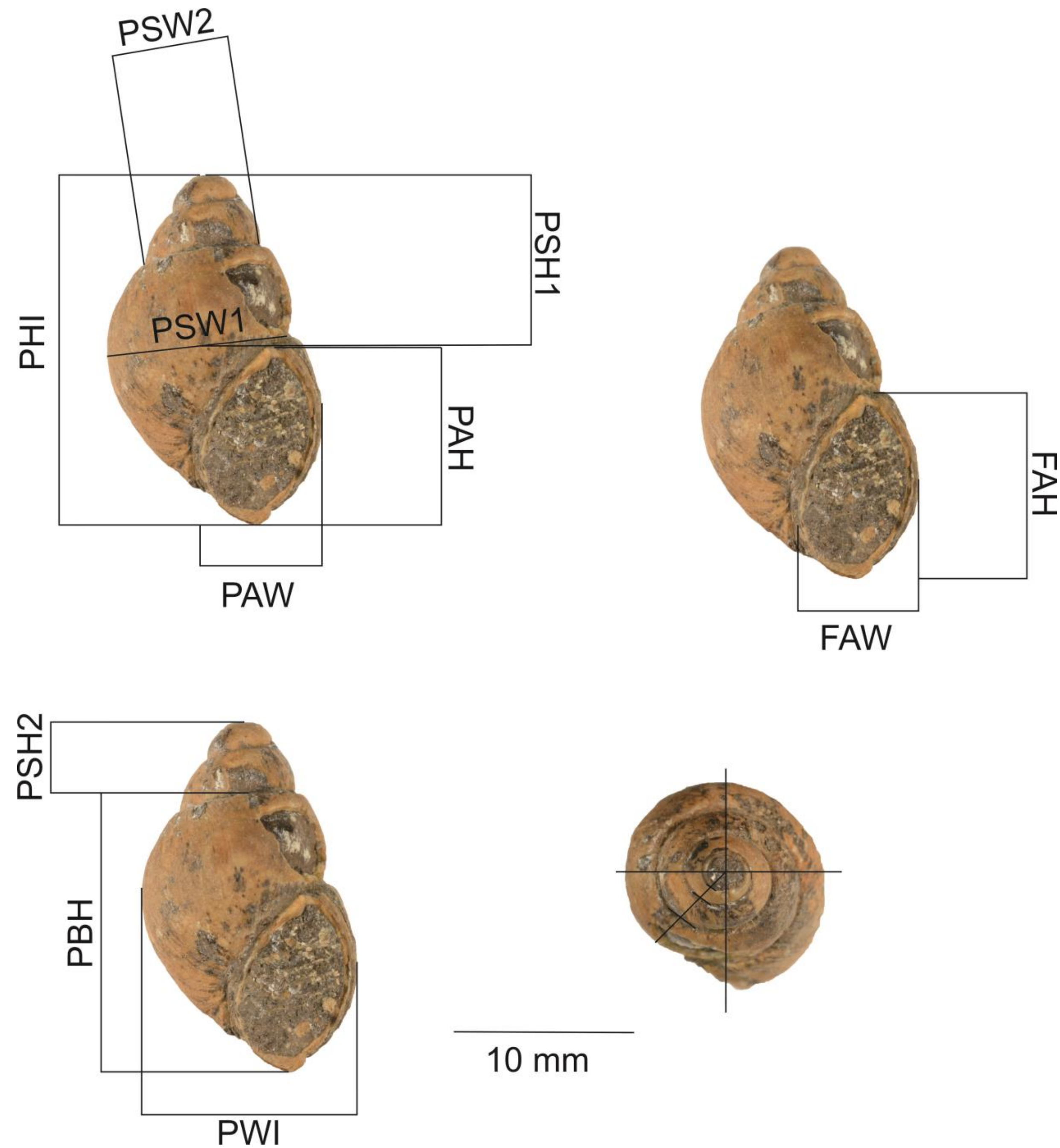


Figure 4. Photos of different snail views and measurements. Views represented here are apertural, apertural flush and apical.

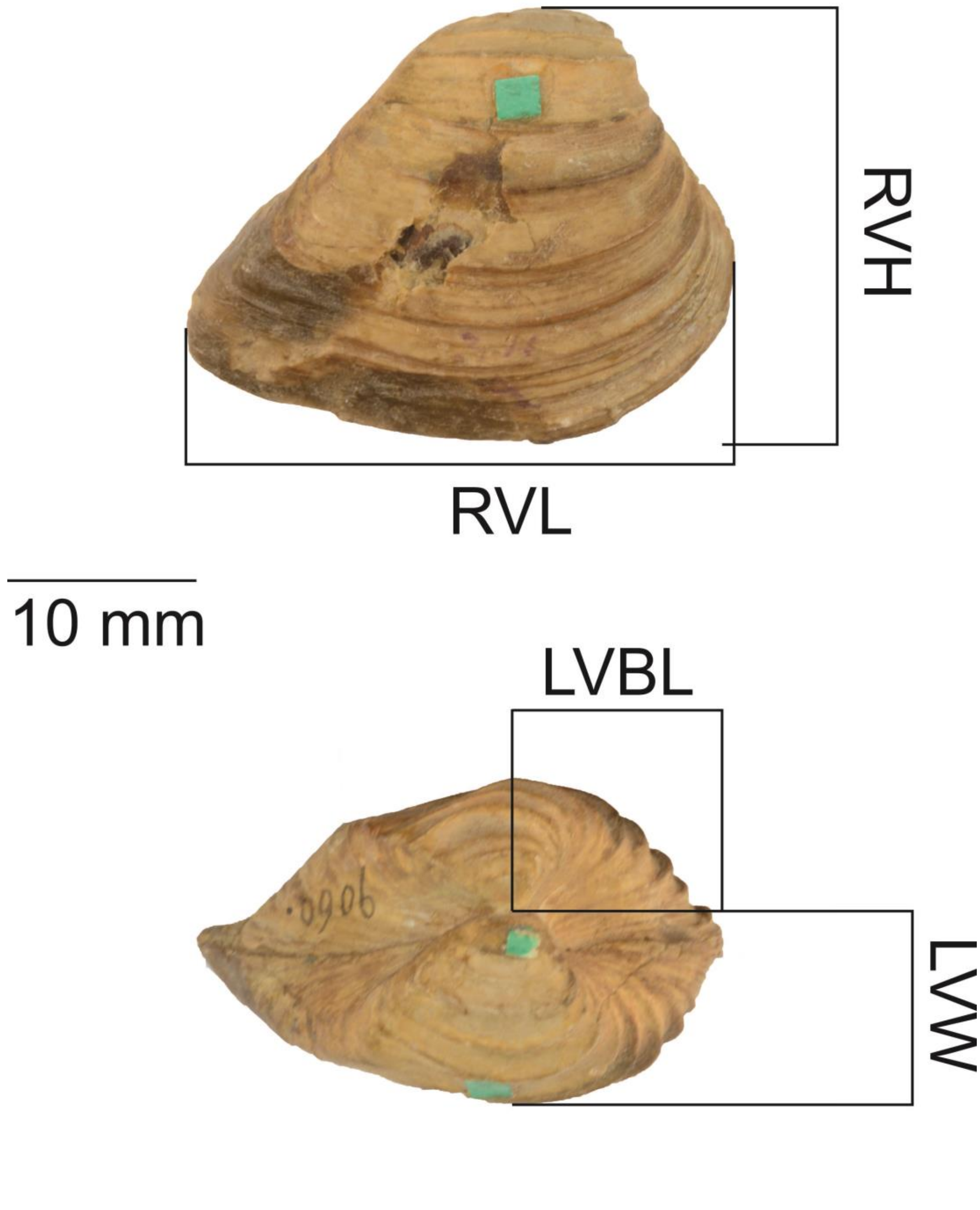


Figure 5. Photos of different clam views and measurements. Views represented are external and dorsal.

Table 2. Table of measurements for clam type and figured specimens. Explanation of each measurement is provided in the text. X represents missing. Measurements in millimeters.

Species	Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
Anodonta propatoris	USNM 29691	X	X	X	X	X	X	X	73.93	31.16	X	30.57	0.42	0.41	X
Anodonta propatoris	USNM 29663	60.62	36.80	14.07	27.77	0.61	0.46	0.23	57.71	34.69	12.28	26.04	0.60	0.45	0.21
Corbicula cytheriformis	USNM 35337	24.48	21.93	7.41	8.31	0.90	0.34	0.30	24.44	21.78	7.63	9.12	0.89	0.37	0.31
Corbicula occidentalis	USNM 2134	24.77	24.88	6.93	11.16	1.00	0.45	0.28	24.53	25.24	9.79	8.93	1.03	0.36	0.40
Corbicula occidentalis	USNM 353341	X	X	X	X	X	X	X	18.34	14.48	X	7.40	0.79	0.40	X
Corbicula occidentalis	USNM 353338	33.04	34.99	10.62	14.36	1.06	0.43	0.32	32.91	35.29	11.49	12.81	1.07	0.39	0.35
Corbula subtrigonalis	15	20.35	X	15.05	X	0.74	X	X	X	X	X	X	X	X	X
Corbula subtrigonalis	11	X	X	6.27	4.93	X	X	X	X	22.65	16.49	4.93	0.73	0.22	X
Corbula subtrigonalis	13	X	X	X	X	X	X	X	X	23.11	15.13	X	0.65	X	X
Corbula subtrigonalis	14	24.47	15.37		X	0.63	X	X	X	X	X	X	X	X	X
Corbula subtrigonalis	10	X	X	X	X	X	X	X	X	19.06	13.60	X	0.71	X	X
Corbula subtrigonalis	17	X	X	X	X	X	X	X	X	10.40	6.40	X	0.62	X	X
Corbula subtrigonalis	16	X	X	X	X	X	X	X	X	11.97	8.73	X	0.73	X	X
Corbula undifera	USNM 9060	30.39	23.83	10.94	10.50	0.78	0.35	0.36	X	X	8.94	10.05	X	X	X
Corbula undifera	2	X	X	6.14	X	X	X	X	16.25	13.25	7.17	7.42	0.82	0.46	0.44
Lampsilis consueta	USNM 29699a	X	X	X	X	X	X	X	X	57.33	32.57	X	X	X	X
Lampsilis consueta	USNM 29699b	X	X	X	X	X	X	X	88.04	54.25	X	X	0.62	X	X
Lampsilis consueta	USNM 29699c	X	X	X	X	X	X	X	88.04	53.57	29.76	X	0.61	0.34	X
Plesielliptio abbreviatus	USNM 30738	57.39	36.47	13.92	21.28	X	X	X	X	X	X	X	X	X	X
Plesielliptio abbreviatus	USNM 29548a	X	X	X	22.29	X	X	X	X	X	X	X	X	X	X
Plesielliptio abbreviatus	USNM 29548b	X	X	X	X	X	X	X	X	X	X	18.63	X	X	X
Plesielliptio abbreviatus	USNM 29548c	X	X	X	9.89	X	X	X	X	X	X	X	X	X	X
Plesielliptio abbreviatus	USNM 29548d	X	X	X	X	X	X	X	X	X	X	8.61	X	X	X
Plesielliptio danae	USNM 2163	84.73	38.37	14.70	16.06	0.45	0.19	0.17	83.80	37.03	13.08	11.40	0.44	0.14	0.16

Table 2. cont.

Species	Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
Plesielliptio danae	USNM 335345	X	X	X	X	X	X	X	77.96	37.02	X	X	0.47	X	X
Plesielliptio danae	USNM 9021	X	X	X	X	X	X	X	75.54	42.51	15.12	8.03	0.56	0.11	0.20
Plesielliptio deweyanus	USNM 2175	X	X	X	X	X	X	X	59.55	X	13.71	2.07	X	0.03	0.23
Plesielliptio deweyanus	USNM 2175a	X	25.53	9.62	6.53	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897a	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897b	X	X	X	4.75	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897c	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897d	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897e	X	X	X	7.10	X	X	X	X	X	X	X	X	X	X
Plesielliptio deweyanus	USNM 353897f	X	X	X	X	X	X	X	X	X	X	3.10	X	X	X
Plesielliptio priscus	USNM 29739a	64.41	32.97	14.71	X	0.51	0.23	X	X	31.29	X	X	X	X	X
Plesielliptio priscus	USNM 29739b	74.29	42.46	15.53	X	0.57	0.21	X	73.80	42.25	10.98	15.11	0.57	0.20	0.15
Plesielliptio stantoni	USNM 358004	81.56	44.87	17.11	13.20	0.55	0.16	0.21	X	X	X	X	X	X	X
Plesielliptio subspatulatus	USNM 2164	71.26	32.85	10.36	6.62	0.46	0.09	0.15	71.59	33.04	7.37	6.83	0.46	0.10	0.10
Plesielliptio subspatulatus	USNM 30739	79.75	35.26	9.31	7.51	0.44	0.09	0.12	78.55	32.23	5.21	7.93	0.41	0.10	0.07
Plesielliptio subspatulatus	USNM 29720a	X	30.55	X	6.40	X	X	X	X	X	X	X	X	X	X
Plesielliptio subspatulatus	USNM 29720b	X	23.85	X	7.65	X	X	X	X	X	X	X	X	X	X
Plesielliptio subspatulatus	USNM 29720c	77.39	34.58	X	7.12	0.45	0.09	X	X	X	X	X	X	X	X
Plesielliptio subspatulatus	USNM 29720d	64.56	32.99	8.12	5.94	0.51	0.09	0.13	63.32	33.73	9.17	5.92	0.53	0.09	0.14
Plesielliptio subspatulatus	USNM 29720e	X	X	X	X	X	X	X	84.50	36.52	X	8.02	0.43	0.09	X
Plesielliptio subspatulatus	USNM 29720f	61.90	30.31	X	5.18	0.49	0.08	X	X	X	X	X	X	X	X
Pleurobema cryptorhynchus	USNM 12503	52.67	37.86	18.34	7.60	X	X	X	X	X	X	X	X	X	X
Pleurobema cryptorhynchus	USNM 12483a	X	X	X	X	X	X	X	X	46.78	X	9.29	X	X	X
Pleurobema cryptorhynchus	USNM 12483b	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quadrula primaevus	USNM 32043	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quadrula primaevus	USNM 12474b	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Table 2. cont.

Species	Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
Quadrula primaevus	USNM 12474a	63.51	X	13.88	23.97	X	0.38	0.22	X	X	X	X	X	X	X
Quadrula primaevus	USNM 12474b	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quadrula primaevus	USNM 12474c	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Quadrula supenawensis	USNM 30736	X	X	X	X	X	X	X	57.85	47.30	X	2.21	0.82	X	X
Rhabdotophorus senectus	USNM 2478a	82.59	41.49	12.46	7.79	0.50	0.09	0.15	X	X	X	X	X	X	X
Rhabdotophorus senectus	USNM 2478b	X	42.16	X	X	X	X	X	X	X	X	X	X	X	X
Rhabdotophorus senectus	USNM 2478c	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Rhabdotophorus senectus	USNM 8141a	X	33.12	X	6.97	X	X	X	X	X	X	X	X	X	X
Rhabdotophorus senectus	USNM 8141b	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sphaerium planum	USNM 2130	9.24	7.91	X	4.59	0.86	0.50	X	X	X	X	X	X	X	X
Sphaerium planum	USNM 2130a	7.84	6.48	X	3.45	0.83	0.44	X	X	X	X	X	X	X	X
Sphaerium planum	USNM 2130b	X	X	X	X	X	X	X	8.12	6.76	1.59	4.44	0.83	0.55	0.20
Sphaerium planum	USNM 25921a	X	X	X	X	X	X	X	11.67	9.19	X	5.02	0.79	0.43	X
Sphaerium planum	USNM 25921b	11.29	9.10	X	5.70	0.81	0.50	X	X	X	X	X	X	X	X
Sphaerium planum	USNM 28682	14.36	10.91	X	6.40	0.76	0.45	X	X	X	X	X	X	X	X
Sphaerium planum	USNM 29505a	X	X	X	X	X	X	X	9.47	7.21	X	4.11	0.76	0.43	X
Sphaerium planum	USNM 29505b	X	X	X	X	X	X	X	10.16	6.93	X	4.31	0.68	0.42	X
Sphaerium planum	USNM 29505c	9.14	6.94	1.84	4.20	0.76	0.46	0.20	X	X	X	X	X	X	X
Sphaerium planum	USNM 29740	X	7.34	2.16	4.29	X	X	X	X	X	X	X	X	X	X
Sphaerium recticardinale	USNM 2129	X	8.72	2.82	X	X	X	X	X	X	X	X	X	X	X
Sphaerium recticardinale	USNM 2129a	14.65	X	X	7.57	X	0.52	X	X	X	X	X	X	X	X
Sphaerium recticardinale	USNM 2129b	14.74	11.07	X	5.73	0.75	0.39	X	X	X	X	X	X	X	X
Sphaerium recticardinale	USNM 2129c	X	X	X	X	X	X	X	11.14	X	X	X	X	X	X
Sphaerium subellipticum	USNM 2128	6.93	4.92	X	2.58	0.71	0.37	X	X	X	X	X	X	X	X
Sphaerium subellipticum	USNM 2128a	X	X	X	X	X	X	X	6.16	4.16	X	X	0.68	X	X

Table 3. Table of measurements for snail type and figured specimens. Explanation of each measurement is provided in the text. X represents missing data. Measurements are in millimeters and degrees respectively. (*) indicates trait reconstructed by previous researchers

Species	Specimen #	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
Aplexa atavus	USNM 12481a	5.21	24.82	48.83	16.08	48.31	13.71	25.96	34.60	11.83	10.90	9.78	22.75	X	X	0.45	1.08	29.56
Aplexa atavus	USNM 12481b	5.72	X	48.03	16.53	48.27	12.71	X	35.56	X	9.78	X	X	X	X	X	X	25.12
Aplexa atavus	USNM 12481c	4	37.00	34.37	16.25	34.37	11.02	21.88	X	15.09	10.98	X	X	X	X	0.69	1.37	28.78
Campeloma vetulum	USNM 29556a	5.86	57.55	23.33	15.68	23.29	5.59	10.97	17.7	12.25	8.19	9.35	12.49	8.91	12.3	1.12	1.50	63.17
Campeloma vetulum	USNM 29556b	5.04	61.44	23.96	16.08	24	5.74	11.16	18.26	13.7	8.55	9.65	13.26	9.74	13.5	1.23	1.60	65.39
Campeloma vetulum	USNM 29556c	5.51	58.47	23.96	16.44	23.87	5.44	11.8	18.54	13.88	8.92	9.9	12.96	9.8	13.2	1.18	1.56	60.59
Campeloma vetulum	USNM 29556d	5.08	53.68	24.25	15.9	24.13	5.44	12.11	18.69	13.26	8.85	9.35	12.63	9.1	12.84	1.09	1.50	57.89
Campeloma vetulum	USNM 29556e	5.23	X	X	15.15	X	X	X	X	X	9.39	X	X	X	X	X	X	58.29
Campeloma vetulum pegmate	USNM 75289	3.96	55.93	19.64	11.96	19.43	3.96	9.27	15.43	9.97	6.57	6.80	9.84	6.63	10.2	1.08	1.52	46.96
"Helix" occidentalis	USNM 2106a	3.91	X	X	7.21	3.68	0.49	X	3.2	X	2.93	X	X	X	X	X	X	134.7
"Helix" occidentalis	USNM 2106b	4.32	120.61	5.28	8.45	5.07	0.56	1.68	4.51	6.07	2.91	4.11	3.71	4.05	4.08	3.61	2.08	134.8
"Helix" occidentalis	USNM 2106c	3.21	X	X	X	X	0.36	X	X	X	1.45	X	X	X	X	X	X	145.9
"Helix" vitrinoides	USNM 2104a	4.78	98.33	10.14	10.8	10.14	1.15	3.68	9.01	9.07	4.12	X	X	X	X	2.46	2.20	115.1
"Helix" vitrinoides	USNM 2104b	X	X	X	X	X	X	X	X	X	6.5	X	X	X	X	X	X	85.87
"Helix" vitrinoides	USNM 2104c	X	105.65	12.44	14.45	12.37	X	3.88	11.75	10.78	3.88	7.88	9.03	X	X	2.78	2.78	128.9
"Helix" vitrinoides	USNM 2104d	X	X	8.69	8.76	8.58	X	X	8.08	X	3.4	5.55	5.47	X	X	X	X	120.9

Table 3. cont.

Species	Specimen #	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
"Hydrobia" subconica	USNM 353606a	3.02	X	X	X	X	1	X	X	X	1.56	X	X	X	X	X	X	57.48
"Hydrobia" subconica	USNM 353606b	4.14	55.56	6.18	4.13	6.23	1.99	3.21	4.24	3.48	2.39	X	X	X	X	1.08	1.46	46.96
"Hydrobia" subcylindrica - ("Hydrobia" recta)	USNM 29586a	6.24	29.53	4.96	2.09	4.96	2.47	3.49	2.23	1.92	1.69	1.08	1.38	X	X	0.55	1.14	23.7
"Hydrobia" subcylindrica - ("Hydrobia" recta)	USNM 29586b	X	X	X	2.74	7	X	4.48	X	X	2.35	X	X	X	X	X	X	17.8
Lioplacodes gracilenta	1	8	X	21.07	7.9	X	12.11	X	8.95	X	6.04	X	X	X	X	X	X	25.03
Lioplacodes gracilenta	2	5	X	15.77	6.05	X	6.47	9.87	9.31	5.22	3.09	X	5.54	X	X	0.53	1.69	23.99
Lioplacodes invenusta	USNM 2144	4.28	33.12	20.84	10.04	20.92	11.78	12.98	9.23	9.27	7.78	6.32	7.01	5.18	6.73	0.71	1.19	29.52
Lioplacodes invenusta	USNM 2144a	5.32	37.63	14.93	7.74	14.89	5.83	9.41	9.06	6.51	5.59	3.99	5.64	4.99	7.03	0.69	1.16	38.11
Lioplacodes invenusta	USNM 2144b	5.62	42.48	19.85	10.15	19.88	7.56	12.16	12.31	9.63	7.44	6.20	7.95	6.30	7.02	0.79	1.29	30.76
Lioplacodes invenusta	USNM 2144c	X	33.64	22.13	9.96	22.05	9.69	14.18	12.36	8.77	8.08	5.90	7.87	X	X	0.62	1.09	21.24
Lioplacodes invenusta	USNM 2144d	X	33.50	21.91	9.67	21.76	8.94	14.84	X	8.21	7.92	4.66	6.93	X	X	0.55	1.04	29.64
Lioplacodes invenusta	USNM 2144e	X	28.76	21.4	9.17	21.31	9.41	14.89	11.9	7.93	7.63	5.07	5.49	X	X	0.53	1.04	29.37
Lioplacodes invenusta	USNM 2144f	X	X	X	X	X	14.64	X	X	X	10.32	X	X	X	X	X	X	30.47
Lioplacodes invenusta	USNM 2144g	X	X	22.27	X	22.27	10.03	X	12.25	X	8.35	X	X	X	X	X	X	32.72
Lioplacodes invenusta	USNM 2144h	X	X	X	X	X	X	X	X	X	6.88	X	X	X	X	X	X	29.49

Table 3. cont.

Species	Specimen #	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
Lioplacodes invenusta	USNM 2144i	X	36.79	21.72	11.01	21.61	8.46	13.3	13.15	9.47	8.09	6.22	8.65	X	X	0.71	1.17	22.92
Lioplacodes invenusta	USNM 2144j	X	X	X	X	X	X	X	13.11	X	7.22	X	X	X	X	X	X	32.78
Lioplacodes invenusta	USNM 2144k	X	X	X	X	X	X	X	X	X	6.14	X	X	X	X	X	X	31.41
Lioplacodes invenusta	USNM 2144l	X	X	X	X	X	X	X	X	X	7.31	X	X	X	X	X	X	20.10
Lioplacodes judithensis	USNM 30741	6	X	X	12.13	18.87	9.16	X	X	9.71	8.45	X	X	X	X	X	X	39.07
Lioplacodes praecursa	CT 501	4.5	38.24	X	10.79	20.25	7.95	12.35	12.3	8.86	6.83	X	X	X	X	0.72	1.30	25.55
Lioplacodes subtortuosa	USNM 19180	X	X	X	4.94	X	X	X	4.91	3.91	2.2	X	X	X	X	X	1.78	37.29
Lioplacodes subtortuosa	USNM 32050a	4.91	50.53	18.66	11.69	18.58	4.66	8.04	13.92	10.54	7.99	6.62	10.43	X	X	1.31	1.32	52.65
Lioplacodes subtortuosa	USNM 32050b	4.56	65.26	11.34	9.13	11.34	3.25	5.08	8.09	6.77	3.75	4.82	X	X	X	1.33	1.81	51.99
Melanoides convexa	USNM 2142	7.59	22.03	38.24	11.93	38.10	21.50	28.79	16.60	11.25	10.31	7.12	9.67	X	X	0.39	1.09	17.62
Melanoides convexa impressa	USNM 2143	5.97	26.53	33.01	10.68	32.96	18.02	23.70	14.94	11.27	8.99	X	X	X	X	0.48	1.25	20.39
Melanoides sublaevis	USNM 2145	5.4	30.61	23.01	9.62	22.96	10.34	15.02	12.63	8.37	6.87	5.35	8.53	5.07	9.1	0.56	1.22	21.14
Melanoides sublaevis	USNM 2145a	X	X	X	10.85	X	X	X	14.2	7.83	X	6.53	9.33	6.67	9.06	X	X	X
Melanoides sublaevis	USNM 2145b	X	X	X	9.54	X	X	X	X	X	6.61	X	X	X	X	X	X	12.29
Melanoides sublaevis	USNM 2145c	X	X	X	X	X	X	X	X	X	6.93	X	X	X	X	X	X	13.06

Table 3. cont.

Species	Specimen #	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
Melanoides sublaevis	USNM 28741	X	27.06	X	X	23.4	9.79	14.46	13.6	7.02	X	X	9.01	X	X	X	X	X
Melanoides sublaevis	USNM 29504	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	28.84
Melanoides? omitta	USNM 2184	4.92	27.08	6.68	2.55	6.61	3.06	4.52	3.55	2.24	1.88	1.25	1.99	1.25	1.98	0.50	1.19	18.4
Physa canadensis tenuis	PC 24	5	30.37	36.29	13.62	36.21	7.37	16.13	28.85	9.15	5.44	X	X	X	X	0.57	1.68	27.93
Physa canadensis tenuis	PC 502	X	X	X	14.7	35.8	6.98	X	28.82	X	6.92	X	X	X	X	X	X	39.52
Physa canadensis tenuis	PC 507	5	43.06	X	14.88	35.4	9.15	17.82	26.24	14.75	9.49	8.03	19.63	X	X	0.83	1.55	42.66
Physa copei	USNM 12470	3.85	46.2	52.64	29.74	52.86	2.11	14.43	50.70	16.14	5.24	18.08*	40.45*	X	X	1.12	3.08	46.4
Physa subelongata	USNM 2118	6.76	40.66	28.46	12.83	28.66	6.93	15.24	21.72	12.22	8.45	X	15.24	X	X	0.80	1.45	52.68
Vitrina obliqua	USNM 2108a	4.35	X	11.67	15.32	11.95	1.48	X	10.47	X	4.26	X	X	X	X	X	X	113.5
Vitrina obliqua	USNM 2108b	3.38	X	13.07	16.33	13.02	3.64	X	9.38	X	8.37	X	X	X	X	X	X	97.03
Vitrina obliqua	USNM 2108c	X	X	9.03	11.38	8.84	1.65	X	7.19	X	4.41	X	X	X	X	X	X	131.6
Vitrina obliqua	USNM 2108d	3.5	X	7.4	8.71	6.86	1.57	X	5.29	X	4.01	X	X	X	X	X	X	112.8
Viviparus conradi	USNM 2156F	3.9	54.5	X	X	19.4	X	X	X	13.4	9.2	X	X	X	X	X	1.46	X
Viviparus conradi	USNM 2156A	2.8	X	X	X	12.5	X	X	X	10.1	5.9	X	X	X	X	X	1.71	X
Viviparus conradi	USNM 2156B	3.5	X	X	X	28.3	X	X	X	17.4	12.2	X	X	X	X	X	1.43	X

Table 3. cont.

Species	Specimen #	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
Viviparus conradi	USNM 2156E	4.0	X	X	X	19.7	X	X	X	15.7	10.7	X	X	X	X	X	1.47	X
Viviparus conradi	USNM 2156H	4.5	49.5	X	X	21.1	X	X	X	13.8	9.7	X	X	X	X	X	1.42	X
Viviparus conradi	USNM 2156I	2.6	51.0	X	X	22.8	X	X	X	16.0	10.2	X	X	X	X	X	1.57	X
Viviparus conradi	USNM 2156J	4.0	55.0	X	X	24.7	X	X	X	12.5	7.8	X	X	X	X	X	1.60	X
Viviparus conradi	USNM 2156K	3.8	56.5	X	X	17.9	X	X	X	12.1	7.7	X	X	X	X	X	1.57	X
Viviparus conradi	USNM 2156L	4.9	57.5	X	X	13.0	X	8.7	x	10.5	6.6	X	X	X	X	1.21	1.59	X
Viviparus montanaensis	USNM 29667a	3.17	X	X	9.61	5.12	1.14	X	3.97	X	1.27	X	X	X	X	X	X	125
Viviparus montanaensis	USNM 29667b	2.96	X	4.32	6.94	4.26	0.89	X	X	X	3.03	X	X	X	X	X	X	135.4
Viviparus nidaga	GSC 6675	4.84	X	30.56	21.2	30.47	7.23	X	23.24	X	11.58	X	X	X	X	X	X	63.6
Viviparus nidaga	GSC 11685	4	48.87	32.36	23.34	31.56	10.96	20.77	20.6	19.27	14.12	12.77	11.99	13.55	16.6	0.93	1.36	59
Viviparus nidaga	DSC 21526	4.5	59.14	40.72	29.25	40.45	11.7	22.94	28.75	26.56	17.9	15.3	18.87	16.11	21.1	1.16	1.48	66.55

Because PSW1 requires an apertural suture to be measured, MSA relies on the presence of that suture. Because of preservation issues, the apertural suture is not always available to measure, so SWA was developed to use the penultimate suture which was typically better preserved. The penultimate suture is more commonly preserved and the measure can be applied to a larger group. MSA and SWA measure the angle made by the spire, but more information is required for accurate spire dimensions. This is why PSW1, PSW2, PSH1 and PSH2 are used. Both height measurements are drawn to different respective width measurements to get two different measures of height, one to the first suture and one ultimately to the apertural suture. These measurements say something different about spire dimensions and how they relate to the last whorl. Two width measurements are used because they measure width at different heights, giving a better indication of spire shape. Additional suture whorls are possible, and may still be used in the study if additional data are needed. Apertural measurements are taken both in the apertural flush and apertural views. This is because some shells can have a retracted aperture and if measurements were taken on the flush view this aspect could go unnoticed. Apertural flush view measurements (FAH and FAW) give a better overall picture of the generating curve's shape than the apertural view measurements (PAH and FAH). PWI (overall width) and PHI (overall height) are measured for an overall understanding of shell size. While not telling very much about actual form, these are still important measurements as size can vary extensively even at the species level. Accumulation of these measurements gives researchers a better understanding of complex shell morphology in a quantitative way, but it is when they are applied to character traits that they become useful.

Character states were created for each snail and clam species from the length and angle measurements and selected traits recognized in this study. Character states use a set of numbers given to a state for each selected trait. For example, height for snails was given three states; small-sized (<10 mm), medium sized (10 to 40 mm), and large-sized (>40 mm). Each state was then given a corresponding trait number; small = 0 medium = 1, large = 2. Each snail shell was assigned a trait number for their overall height. The same process was conducted for traits that are not measurable, such as snail whorl convexity. In this example, convexity is subdivided into four states; 0 = flattened, 1 = lightly convex, 2 = convex, 3 = round. Using this method for every selected trait creates a distinct set of traits for each individual species of snail and clam known to the Judith River Formation. Selected traits can be found in Tables 4 and 5. Instances where a trait was not observed or identifiable, a “?” was entered to represent missing data. Character traits for the type specimens are found in tables 6 and 7.

Chosen character traits were based on previous work by Hartman (2015) and Burch (1989) for snails, while work by Hartman and Bogan (in prep.) was used for clams. Hartman and Bogan (2014) and Burch (1989) used extant specimens, which includes extensive soft-part morphology in its assessment that could not be used in an analysis exclusively of fossil specimens. Soft traits are a large part of the trait analysis done on extant mollusks and so the number of traits available is much reduced particularly in the study of continental freshwater snail taxa. Characters are listed with their respective number in the text; refer to figures 4 and 5.

The first character trait used for snails (Table 4) was coiling direction (34), divided into sinistral and dextral. Coiling helps eliminate certain uncommon sinistral families such as *Physa*. Overall shell height (1) was measured and separated into small, medium and large. Number of shell whorls (2) was measured because it can be a diagnostic trait for certain genera, and number of preserved whorls aids in determining completeness of the shell when working with height measurements. Shell width to maximum height (3) was measured to quantify how broad or squat the general shape was. This trait is related to shell shape (a trait that was also examined), so its usefulness is still unknown. Thickness of the shell wall (4) was described. Apical tip shape (6) and apical tip preservation (5) were described, though the usefulness in whether the apical tip is preserved or not is yet to be determined for diagnostics. General shell shape (7) was measured to separate out certain groups, some examples are narrowly conic, elongate conic, conic, ovately conic and broadly conic. Mean spire angle was described and binned for specimens with both a preserved tip (8) (a more accurate measurement) and with a broken tip (9) (less accurate measurement). Spire elevation was categorized (10), based upon typical specimens, as genera such as *Melanoides* tend to have elongate spires compared to other genera. Spire height to body height (11) was categorized. The ratio of spire width to spire height (12) was measured to get a quantitative way of separating general spire shape. Teleoconch whorl shape (13) was categorized for convexity, and change in whorl shape (14). Basal periphery shape (15) was categorized into rounded, and sharp. Suture impressions (16) were characterized as shallow or deep. Shell sculpture was organized into multiple sections: presence and absence of lirae and striae (17, 18), strength of the sculpture (19), if a pattern change was exhibited (20), node development (21), if sculpture was axial or revolving (32, 33) and if any sculpture is exhibited below the periphery of the shell (22). These traits are indicative of many different genera. Examples of these are axial sculpture on *Melanoides*, and revolving striae on *Lioplacodes judithensis*. Shell shouldering (23) was examined for presence and absence, and whether a sinus was present (24). Umbilicus coverage (25) was categorized as it can be diagnostic to certain genera. Aperture shape (26) was measured based on many traits; general shape (round, D-shaped), parietal lip shape (27), basal lip shape (28), width to height ratios both in apertural view (29) and the apertural flush view (30) as this gives a more accurate measurement of actual size. Spire width angle (31) was measured to determine general shell shape and spire shape and its relation to the body whorl.

Mussel measurement character traits include (Table 5) length (1) of the shell separates elongate shells from subrounded and rounded shells and adult shells that are naturally small. Valve length was subdivided in small, medium, long, and very long. The ratio between shell height and shell length (2) was used to determine general shape of the shell, with more elongate shells having a lower value and equidimensional shells a higher value. Whether the two valves were symmetrical (3) was noted. In addition to measurements, general shape of the shell (4) was described based on selected species that best exhibit specific traits. Shape examples of these descriptions include ovate, trianguloid, broadly ovate, rectanguloid, and elongate. This method of using a specimen best describing specific traits was used for all numeric traits. Examples of general shape of external shell margins include dorsal valve margin straight (5), ventral margin (6) broadly convex, and posterior valve (8) and anterior (7) valve margin with abrupt curvature change. Umbo cavity shape (9) and curvature (10) were categorized as shallow and deep. Umbonal and other dorsal sculpture were described based on location (13), prominence (14), and general shape (11, 12). Significantly, sculptural features have been used in assigning species to mussel genera (e.g., Russell, 1931). Sculpture is recognized by its strength (weak and strong), preservation quality (weak and strong), and kind (frequently compared to known genera, e.g., *Plesielliptio*, *Rhabdotophorus*, *Quadrula*). Beaks and beak (umbo) direction (16) could be placed terminally to the central, with posterior direction. Beak and umbo height above dorsal margin (15) was categorized to low on the margin, moderately raised on the margin, and pronounced on the margin. Examples of growth lines (19) strength categories are not evident, obviously present, and growth lines of varying prominence. Examples of Preumbonal sculpture (17) include ridges or chevrons. Examples of postumbonal (18) sculpture include absent, radial lines, and ridges. Extent of sculpture on the disc (20) was categorized. Disc sculpture was categorized into ridges (21) and striate (22). Posterior disc slope curvature (23) was categorized gentle, noticeable, abrupt and vertical. If the posterior disc slope curvature is associated with a ridge (24) was noted. Presence and absence of a ligament (25) was noted. Other features seen in dorsal view include the lunule (26) and escutcheon (27), which were described as long, short, narrow or wide. Ventral view linearity (30) was categorized and straight, curved or crenulated.

Cavity volume (32) was described as shallow, medium, and deep, and cavity shape (31) was described as long and curved or short and deep. Hinge plate shape is described as narrow or wide (33), curve or straight (34), highly developed, or poorly developed (35). Traits associated with cardinal teeth include; hinge strength (36) number of teeth (37, 59), their preservation (38, 60), level of development (complexity) (42, 47, 62), shape (40, 45, 61), height (short or tall) (41, 46, 64), strength (fragile to massive) (39, 44, 63) and orientation (43, 48, 65). As each value has different features, each value was characterized. Traits representing lateral teeth include their number (49, 66), strength (50, 68), length (51, 69), orientation (52) and sculpture (67). The posterior (53, 55) and anterior (54, 56) sockets were described. Interdentum length was categorized (57). Presence and absence of the accessory dentacle was noted (58). Muscle scars were described using location (75), shape (71), size (72, 76, 81, 85), depth (73, 79), preservation quality (77, 83, 86), number (70), and complexity (74, 78, 80, 84, 87). Strength of the pallial line (88) was categorized as weak, moderately strong, and strong.

Phylogenetic Analysis

Phylogenetic trees were constructed for both bivalves and gastropods, using character described. This was done using the program MacClade (Maddison and Maddison, 2005) to write out all the codes and PAUP* (Swofford, 2002) was used to run the analysis. Unknowns with identical traits were eliminated within a locality as it can be assumed that an animal with the same character traits at a locality would be the same species. Matching specimens from separate localities were still included to ensure that all species were represented.

A heuristic search was done to identify unknowns using 100 replicates to create trees, which would then be analyzed. Majority rule was then used to create a majority rule consensus tree, which encompassed all the trees decisions into one final tree using classifications that the majority of trees produced. Revisions were performed on the data sets based on comparisons made when looking over the trees. These were commonly either trait identification error of the researcher's part or binning issues where some specimens would be larger or smaller than the bin most their suspected species were placed in. Additional traits were also added (included in initial description) based on observations where certain genera were not separating as intended. The purpose of this analysis was not to determine phylogenetic lineage or connection, but to accurately diagnose a species based off a set number of character traits.

Table 4. Snail characters used in the final analysis. Numbers define separate character states, bins for measurements and references for categorical traits presented. CI represents Consistency Index, RI represents Retention index.

Character	States	References/Bins	CI	RI
1. Shell size (mm)	0= Small 1= Medium 2= Large	0= 0 to 15 mm 1= 15 to 30 mm 2= 30+ mm	0.25	0.74
2. Shell # whorls; usually	0= Few 1= Average 2= Many	0= 0 to 3 1= 3 to 6 2= 6+	0.15	0.62
3. Shell width-to-maximum height ratio	0= Small 1= Medium 2= Large	0= 0 to 0.5 1= 0.5 to 1 2= 1+	0.4	0.87
4. Shell wall thickness	0= Thin 1= Robust	0= See "*Hydrobia" subconica* 1= See *Viviparus nidaga*	0.2	0.76
5.Apical tip preservation	0= Preserved 1= Broken	N/A	0.1	0.64
6. Apical tip shape	0= Rounded 1= Sharp	0= See *Viviparus montanaensis* 1= See *Viviparus conradi*	0.33	0
7. Shell shape	0= Narrowly conic 1= Elongate conic 2= Conic 3= Ovately conic 4= Broadly conic 5= Lymneaform	0= See *Melanoides convexa* 1= See *Aplexa atavus* 2= See *Lioplacodes judithensis* 3= See *Lioplacodes invenusta* 4= See *Viviparus montanaensis* 5= See *Physa canadensis tenuis*	0.5	0.71
8. Mean spire angle (degrees) for specimens with a complete apex	0= Small 1= Medium 2= Large	0= 0° to 20° 1= 20° to 60° 2= 60°+	0.5	0.6
9. Mean spire angle for specimens with an incomplete apex	0= Small 1= Medium 2= Large	0= 20° 1= 20° to 60° 2= 60°+	0.5	0.71
10. Spire elevation	0= Depressed 1= Not very elevated 2= Elevated 3= Very elevated	0= See *Physa copei* 1= See *Lioplacodes subtortuosa* 2= See *Lioplacodes judithensis* 3= See *Melanoides convexa*	0.38	0.75
11. Spire height to body [whorl] height ratio	0= Small 1= Medium 2= Large	0= 0 to 0.4 1= 0.4 to 0.8 2= 0.8 +	0.25	0.61
12. Mean spire width to mean spire height ratio	0= Small 1= Medium 2= Large	0= 0 to 0.75 1= 0.75 to 1.5 2= 1.5 +	0.33	0.82
13. Teleoconch whorl shape	0= Flattened 1= Lightly convex 2= Convex 3= Rounded	0= See *"Hydrobia" subconica* 1= See *Aplexa atavus* 2= See *Physa copei* 3= See *Lioplacodes judithensis*	0.27	0.71
14. Changing whorl shape	0= None 1= Change	N/A	0.4	0.25

Table 4. cont.

Character	States	References/Bins	CI	RI
15. Basal periphery shape	0= Sharply rounded 1= Narrowly rounded 2= Rounded	0= See *Physa copei* 1= See "*Hydrobia"subconica* 2= See *Physa canadensis tenuis*	0.18	0.53
16. Suture impression	0= Shallow 1= Lightly impressed 2= Impressed 3= Deeply impressed	0= See *Aplexa atavus* 1= See *Melanoides convexa impressa* 2= See *Vitrina obliqua* 3= See *Lioplacodes judithensis*	0.27	0.7
17. Surface sculpture type lirae	0= Absent 1= Present	N/A	1	0
18. Surface sculpture type 2 - Striae	0= Absent 1= Present	N/A	0.5	0
19. Surface sculpture strength	0= Absent 1= Weak 2= Robust	N/A	1	0
20. Surface sculpture pattern change	0= Absent 1= Present	N/A	1	0
21. Node development	0= Absent 1= Present	N/A	0	0
22. Sculpture below periphery	0= Absent 1= Present	N/A	0	0
23. Shell shouldering	0= Absent 1= Present	N/A	0.5	0.75
24. Shoulder with sinus	0= Absent 1= Present	N/A	0	0
25. Umbilicus	0= Closed 1= Opened 2= Covered 3= Broadly ovate 4= D-shaped	0= See *Viviparus conradi* 1= See *Lioplacodes invenusta* 2= See *Melanoides convexa* 3= See S14265 4= No specimen associated	0.5	0.7
26. Aperture shape	0= Round 1= Narrow ovate 2= Ovate 3= Broadly ovate 4= D-shaped	0= See *Viviparus nidaga* 1= See *Physa canadensis tenuis* 2= See "*Hydrobia" subconica* 3= See S14265 4= No specimen associated	0.5	0.7
27. Aperture parietal area	0= Lip weak, not reflexed 1= Lip weak, reflexed 2= Lip strong, not reflexed 3= Lip strong reflexed	0= See *Aplexa atavus* 1= See S14235 2= See *Campeloma vetulum pegmate* 3= See S15403	0.4	0.73

Table 4. cont.

Character	States	References/Bins	CI	RI
28. Aperture basal lip	0= Lip weak, not reflexed 1= Lip weak, reflexed 2= Lip strong, not reflexed 3= Lip strong reflexed	0= See *Lioplacodes invenusta* 1= See *Lioplacodes gracilenta* 2= See "*Helix" occidentalis* 3= See S15399	0.43	0.71
29. Aperture width to height ratio measured in plane of aperture	0= Small 1= Medium 2= Large	0= 0 to 0.6 1= 0.6 to 0. 8 2= 0.8+	0.5	0.6
30. Aperture width to height ratio measured in plane of coiling axis	0= Small 1= Medium 2= Large	0= 0 to 0.6 1= 0.6 to 0. 8 2= 0.8+	0.22	0.46
31. Spire width angle (degrees)	0= Small 1= Medium 2= Large	0= 0° to 30° 1= 30° to 60° 2= 60° +	0.25	0.74
32. Axial Sculpture	0= Absent 1= Present	N/A	1	1
33. Axial Sculpture Type	0=Absent, 1= Nodes 2= Lines	0= See *Lioplacodes invenusta* 1= No specimen associated 2= See *Melanoides convexa*	1	1
34. Coiling	0= Dextral 1= Sinistral	0= See *Lioplacodes invenusta* 1= See *Physa copei*	0.33	0.33

Table 5. Snail characters used in the final analysis. Numbers define separate character states, bins for measurements and references for categorical traits presented. CI represents Consistency Index, RI represents Retention index.

Character	States	References/Bins	CI	RI
1. Shell overall size (Length)	0= Short 1= Medium 2= Long 3= Very long	0= 0 mm to 15 mm 1= 15 mm to 30 mm 2= 30 mm to 70 mm 3= 70+ mm	0.33	0.91
2. Shell size (Height/Length) (H/L)	0= Small 1= Medium 2= Large	0= 0 to 0.6 1= 0.6 to 0.8 2= 0.8 +	0.83	0.83
3. Valves symmetrical	1= Valves not symmetrical 2= Valves symmetrical	N/A	0	0
4. Valve shape general	1= Spherical/circular/orbiculoid 2= Subcircular/subovate 3= Ovate 4= Elliptical, elongate 5= Trianguloid 6= Lanceolate 7= Broadly ovate 8= Trapezoidal 9= Rectilinear	1= See *Sphaerium planum* 2= See *Quadrula primaevus* 3= See *Sphaerium subellipticum* 4= *Rhabdotophorus senectus* 5= *See Corbula subtrigonalis* 6= See s15415 7= No specimen associated 8= See *Corbula undifera* 9= See *Sphaerium recticardinale*	0.62	0.88
5. Dorsal valve margin general shape	1= Dorsal valve margin straight/nearly straight 2= Dorsal valve margin broadly convex 3= Dorsal valve margin with marked curvature change 4= Dorsal valve margin with abrupt curvature change	1= See *Anodonta propatoris* 2= See *Quadrula primaevus* 3= No specimen association 4= See Corbula subtrigonalis	0.29	0.84
6. Ventral valve margin general shape	1= Ventral valve margin straight/nearly straight 2= Ventral valve margin broadly convex 3= Ventral valve margin with marked curvature change 4= Ventral valve margin with abrupt curvature change 5= Ventral valve margin undulated or crenulated	1= See *Rhabdotophorus senectus* 2= See *Plesielliptio stantoni* 3= No specimen association 4= No specimen association 5= See *Plesielliptio danae*	0.67	0.75
7. Anterior valve margin general shape	1=Dorsal valve margin straight/nearly straight 2= Dorsal valve margin broadly convex 3= Dorsal valve margin with marked curvature change 4= Dorsal valve margin with abrupt curvature change	1= No specimen association 2= See *Corbula subtrigonalis* 3= No specimen association 4= No specimen association	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
8. Posterior valve margin general shape	1= Posterior valve margin straight/nearly straight 2= Posterior valve margin broadly convex; 3= Posterior valve margin with marked curvature change 4= Posterior valve margin with abrupt curvature change	1= No specimen association 2= See *Quadrula primaevus* 3= See *Corbula undifera* 4= See *Corbula subtrigonalis*	0.5	0.93
9. Umbo shape	1= Umbo narrow 2= Umbo broad	1= See *Corbula subtrigonalis* 2= See *Plesielliptio stantoni*	0.33	0.93
10. Umbo curvature	1= Beaks very little incurved 2= Beaks slightly incurved 3= Beaks somewhat incurved 4= Beaks incurved 5= Beaks strongly incurved, enrolled 6= Beaks depressed	1= See *Corbula subtrigonalis* 2= See *Plesielliptio priscus* 3= See S15386 4= See *Corbula undifera* 5= See *Quadrula supenawensis*	0.33	0.6
11. Umbo sculpture type	0= No sculpture (growth lines only) 1= Sculpture simple loop 2= Sculpture double looped 3= Sculpture concentric bars/undulations 4= Sculpture radial 5= Sculpture chevron (zigzag) 6= Curving ridges	0= See *Corbula subtrigonalis* 1= See *Plesielliptio subspatulatus* 2= See S15387 3= See S15508 4= No specimen association 5= No specimen association 6= See *Plesielliptio abbreviatus*	0.8	0.89
12. Umbo genus sculpture type (Shell disk sculpture)	1= Plesielliptio-like 2= Rhabdotophorus-like 3= Proparreysia-like 4= Monsordinatus-like 5= Dorsoanastomoses-like	1= See *Plesielliptio abbreviatus*; 2= See *Rhabdotophorus senectus* 3= No specimens associated 4= No specimens associated 5= No specimens associated	1	0
13. Extent of sculpture on umbo (Distance from beak)	1= Umbo-beak without sculpture 2= Sculpture restricted to beak 3= Sculpture covers umbo	1= See *Corbula subtrigonalis* 2= No specimens associated 3= See *Plesielliptio subspatulatus*	0.67	0.91
14. Strength of sculpture on umbo	1= No sculpture 2= Very subtle 3= Typically poorly developed/preserved 4= Well developed	1= See *Corbula subtrigonalis* 2= See *Plesielliptio subspatulatus* 3= See S15508 4= No specimen association	0.67	0.9

Table 5. cont.

Character	States	References/Bins	CI	RI
15. Beak height above dorsal margin (peak prominence)	1= Beaks depressed, not prominent 2= Beaks enrolled 3= Beaks low relative to dorsal margin 4= Beaks moderately elevated relative to dorsal margin 5= Beaks elevated (prominent) relative to dorsal margin	1= See *Corbula subtrigonalis* 2= See s15349 3= See s15386 4= See *Plesielliptio subspatulatus* 5= No specimens associated	0.57	0.92
16. Beak position along dorsal margin	1= Beak position near terminal anterior on dorsum 2= Beak position well anterior (forward) of middle on dorsum 3= Beak position anterior (advance) of middle on dorsum 4= Beak position very near middle on dorsum 5= Beak position central, middle on dorsum 6= Beak position posterior (behind) of middle on dorsum 7= Beak position near terminal posterior on dorsum	1= See *Plesielliptio subspatulatus* 2= See *Sphaerium recticardinale* 3= See *Sphaerium subellipticum* 4= See *Corbula subtrigonalis* 5= See *Anodonta propatoris* 6= No specimens associated 7= No specimens associated	0.22	0.63
17. Preumbonal sculpture	1= Preumbonal sculpture absent 2= Preumbonal sculpture chevron 3= Preumbonal sculpture ridges	1= No specimens associated 2= No specimens associated 3= No specimens associated	0.33	0.83
18. Postumbonal sculpture	1= Postumbonal absent 2= Postumbonal anastomosing lines ("Quadrula") 3= Postumbonal Rhabdotophorus-type ridges 4= Postumbonal Plesielliptio-type postero-divergent ridges 5= Postumbonal Monsordinatus nodules ("Plethobasus") 6= Postumbonal Monsordinatus ridges ("Plethobasus") 7= Postumbonal Proparreysia-type ridges/plications	1= See *Corbula subtrigonalis* 2= See *Quadrula primaevus* 3= See *Rhabdotophorus senectus* 4= See *Plesielliptio danae* 5= No specimens associated 6= No specimens associated 7= No specimens associated	0.5	0.79
19. Growth lines	1= Growth lines effectively absent to view (smooth shell) 2= Growth lines finely divided 3= Growth lines obviously present, evenly distributed 4= Growth line pattern with stage of growth change indicated 5= Growth lines of varying prominence 6= Growth lines obviously present, stronger (coarser) at margin	1= See *Sphaerium subellipticum* 2= See *Lampsilis consueta* 3= No specimens associated 4= See *Quadrula supenawensis* 5= See *Corbula subtrigonalis* 6= See *Plesielliptio subspatulatus*	0.5	0.83
20. Extent of sculpture extent on disc	0= No sculpture on shell 1= Disc sculpture limited to umbo 2= Disc sculpture about 1/4 way down disc 3= Disc sculpture about 1/3 to 1/2 way down disc	0= See *Corbula subtrigonalis* 1= No specimen associated 2= No specimen associated 3= See *Plesielliptio subspatulatus*	0.67	0.92

Table 5. cont.

Character	States	References/Bins	CI	RI
21. Shell disc sculpture - ridges	0= No lirae or ridges 1= Plications 2= Radial lines 3= Curving ridges	0= See *Corbula subtrigonalis* 1= No specimens associated 2= See *Plesielliptio subspatulatus* 3= See S15508	0	0
22. Shell disc sculpture – striate	0= Striae absent 1= With a few striae 2= With numerous striae	0= See *Corbula subtrigonalis* 1= No specimens associated 2= No specimens associated	0.27	0.8
23. Posterior disc slope curvature	1= Posterior disc slope ridge absent = gentle curvature 2= Posterior disc slope curvature change noticeable 3= Posterior disc slope curvature abrupt 4= Posterior disc slope curvature vertical	1= See *Sphaerium subellipticum* 2= See *Sphaerium recticardinale* 3= See *Corbula subtrigonalis* 4= See *Corbula undifera*	0.17	0.83
24. Posterior disc curvature slope change with elevated ridge (like holmesiana)	1= Posterior disc slope associated with no ridge on curvature change 2= Posterior disc slope associated with ridge on curvature change	1= See *Quadrula primaevus* 2= See *Plesielliptio stantoni*	0.33	0.5
25. Ligament presence/absence	1= Ligament absent 2= Ligament present	1= See *Corbula subtrigonalis* 2= See *Quadrula primaevus*	0.33	0
26. Lunule shape	1= Lunule narrow 2= Lunule narrowly ovoid 3= Lunule lanceolate	1= See *Corbula subtrigonalis* 2= See *Corbicula cytheriformis* 3= No specimen associated	0.5	0
27. Lunule length	1= Lunule short 2= Lunule long	1= See *Corbula subtrigonalis* 2= See *Plesielliptio priscus*	0	0
28. Escutcheon shape	1= Escutcheon narrow 2= Escutcheon lanceolate/lancet-shaped	1= See *Corbula subtrigonalis* 2= No specimen associated	0.5	0.93
29. Escutcheon length	1= Escutcheon short 2= Escutcheon long	1= See *Corbula subtrigonalis* 2= See *Plesielliptio priscus*	0	0
30. Ventral view linearity	1= Ventral view of margin straight 2= Ventral view of margin curvy 3= Ventral view of margin crenulated	1= See *Corbula subtrigonalis* 2= See *Plesielliptio stantoni* 3= No specimen associated	0.5	0.5

Table 5. cont.

Character	States	References/Bins	CI	RI
31. Umbonal cavity shape	1= Umbonal cavity shape long and curved 2= Umbonal cavity shape short and deep	1= *See Plesielliptio subspatulatus* 2= See *Quadrula supenawensis*	0.5	0
32. Umbonal cavity size (volume) range	1= Umbonal cavity volume small/poorly developed 2= Umbonal cavity volume medium 3= Umbonal cavity volume large 4= Umbonal cavity volume very large	1= See *Plesielliptio deweyanus* 2= See *Quadrula primaevus* 3= See *Quadrula supenawensis* 4= No specimen associated	0.5	0.33
33. Hinge plate width	1= Hinge plate absent 2= Hinge plate narrow 3= Hinge plate moderately wide/relatively wide 4= Hinge plate wide/broad	1= See s15508 2= See *Quadrula primaevus* 3= See *Quadrula supenawensis* 4= See *Plesielliptio danae*	0.67	0.75
34. Hinge plate curvature/shape	1= Hinge plate straight or nearly straight 2= Hinge plate slightly curved 3= Hinge plate curved 4= Hinge plate strongly bent/inclined/curved	1= See *Pleurobema cryptorhynchus* 2= See *Quadrula primaevus* 3= See *Quadrula supenawensis* 4= No specimen associated	0.5	0.33
35. Hinge plate development	0= Hinge plate absent 1= Hinge plate lightly developed 2= Hinge plate moderately developed 3= Hinge plate thickened/heavily developed	0= See *Rhabdotophorus senectus* 1= See *Quadrula primaevus* 2= See *Plesielliptio danae* 3= No specimen associated	0.6	0.6
36. Cardinal teeth hinge strength	0= Cardinal teeth absent 1= Cardinal teeth weakly developed 2= Cardinal teeth moderate strength/development 3= Cardinal teeth strongly developed	0= See *Plesielliptio danae* 1= See S15361 2= See *Quadrula supenawensis* 3= See *Plesielliptio deweyanus*	0	0
37. Left valve cardinal number of teeth	0= Left valve posterior cardinal number of teeth 0 1= Left valve posterior cardinal number of teeth 1 2= Left valve posterior cardinal number of teeth 2	0= No specimen associated 1= See *Pleurobema cryptorhynchus* 2= See *Quadrula supenawensis*	1	0
38. Left valve cardinal taphonomy/preservation	0= Left valve cardinal tooth taphonomy uninterpretable 1= Left valve cardinal tooth taphonomy poorly preserved (heavily worn) 2= Left valve cardinal tooth taphonomy decently preserved 3= Left valve cardinal tooth taphonomy well preserved (pristine)	0= No specimen associated 1= See *Pleurobema cryptorhynchus* 2= See *Quadrula supenawensis* 3= See S15347	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
39. Left valve posterior cardinal (or single) tooth mass	1= Left valve posterior (or single) cardinal tooth mass delicate light 2= Left valve posterior (or single) cardinal tooth mass moderate 3= Left valve posterior (or single) cardinal tooth mass heavy	1= See S15525 2= See *Quadrula supenawensis* 3= See *Plesielliptio deweyanus*	0.67	0.75
40. Left valve posterior cardinal (or single) tooth shape	0= Not applicable 1= Left valve posterior (or single) cardinal tooth shape trianguloid/triangularly 2= Left valve posterior (or single) cardinal tooth shape pyramidoid 3= Left valve posterior (or single) cardinal tooth shape peg-like/conoid	0= No specimen associated 1= See *Plesielliptio danae* 2= See *Plesielliptio subspatulatus* 3= See S15387	0.5	0.67
41. Left valve posterior cardinal (or single) tooth height	1= Left valve posterior (or single) cardinal tooth least height 2= Left valve posterior (or single) cardinal tooth moderate height 3= Left valve posterior (or single) cardinal tooth greatest height	1= See S15525 2= See *Plesielliptio subspatulatus* 3= See S15350	1	1
42. Left valve posterior cardinal (or single) tooth structure (grooves)	1= Left valve posterior (or single) cardinal tooth structure simple (no grooves, few grooves) 2= Left valve posterior (or single) cardinal tooth structure moderate 3= Left valve posterior (or single) cardinal tooth structure complex	1= See S15525 2= No specimen associated 3= See *Quadrula supenawensis*	1	1
43. Left valve posterior cardinal (or single) tooth orientation	1= Left valve posterior (or single) cardinal tooth oriented oblique anterior 2= Left valve posterior (or single) cardinal tooth oriented oblique posterior 3= Left valve posterior (or single) cardinal tooth oriented vertical (to dorsal margin) 4= Left valve posterior (or single) cardinal tooth oriented parallel (to dorsal margin)	1= See *Plesielliptio danae* 2= No specimen associated 3= No specimen associated 4= See *Quadrula supenawensis*	0.5	0
44. Left valve anterior cardinal tooth mass	0= Left valve anterior cardinal tooth absent; 1= Left valve anterior cardinal tooth mass delicate/light/reduced 2= Left valve anterior cardinal tooth mass moderate 3= Left valve anterior cardinal tooth mass heavy	0= No specimen associated 1= See *Quadrula supenawensis* 2= See *Plesielliptio subspatulatus* 3= See *Plesielliptio abbreviatus*	0.67	0.67
45. Left valve anterior (or single) cardinal tooth shape	1= Left valve anterior cardinal tooth shape trianguloid 2= Left valve anterior cardinal tooth shape pyramidoid 3= Left valve anterior cardinal tooth shape peg-like/conoid	1= See *Quadrula supenawensis* 2= See *Plesielliptio subspatulatus* 3= See S15344	1	1

Table 5. cont.

Character	States	References/Bins	CI	RI
46. Left valve anterior (or single) cardinal tooth height	1= Left valve anterior cardinal tooth least height 2= Left valve anterior cardinal tooth moderate height 3= Left valve anterior cardinal tooth greatest height	1= See *Pleurobema cryptorhynchus* 2= See *Quadrula supenawensis* 3= See S15350	1	1
47. Left valve anterior (or single) cardinal tooth structure (grooves)	1= Left valve anterior cardinal tooth structure simple (no ridges to few number of ridges) 2= Left valve anterior cardinal tooth structure moderate 3= Left valve anterior cardinal tooth structure complex	1= See S15525 2= No specimen associated 3= See *Quadrula supenawensis*	1	1
48. Left valve anterior (or single) cardinal orientation	1= Left valve anterior cardinal tooth oriented oblique anterior 2= Left valve anterior cardinal tooth oriented oblique posterior 3= Left valve anterior cardinal tooth oriented vertical (to dorsal margin) 4= Left valve anterior cardinal tooth oriented parallel (to dorsal margin)	1= See *Quadrula supenawensis* 2= No specimen associated 3= See *Plesielliptio deweyanus* 4= See *Plesielliptio subspatulatus*	0.67	0.5
49. Left valve lateral tooth number	0= Left valve laterals teeth absent 1= Left valve lateral tooth number 1 2= Left valve lateral teeth number 2	0= See *Pleurobema cryptorhynchus* 1= See S15344 2= See *Quadrula supenawensis*	1	0
50. Left valve lateral teeth strength	0= Left valve lateral teeth strength absent 1= Left valve lateral teeth strength weak 2= Left valve lateral teeth strength strong	0= See *Pleurobema cryptorhynchus* 1= See S15344 2= See *Quadrula supenawensis*	1	0
51. Left valve lateral teeth length	0= Left valve lateral teeth absent 1= Left valve lateral teeth length short 2= Left valve lateral teeth of medium length 3= Left valve lateral teeth length relatively long 4= Left valve lateral teeth length long	0= See *Pleurobema cryptorhynchus* 1= No specimen associated 2= No specimen associated 3= See *Plesielliptio subspatulatus* 4= See *Quadrula supenawensis*	1	0
52. Left valve lateral teeth orientation	0= Left valve lateral teeth absent 1= Left valve lateral teeth orientation straight or only slightly curved 2= Left valve lateral teeth orientation moderately curved acute < 70 dg) 3= Left valve lateral teeth orientation strongly curved (>70 to 90 dg) 4= Left valve lateral teeth orientation very strongly curved (>90 up to 180 dg)	0= See *Pleurobema cryptorhynchus* 1= See *Plesielliptio subspatulatus* 2= See *Quadrula supenawensis* 3= No specimen associated 4= No specimen associated	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
53. Left valve (posterior) socket shape	1= Left valve (posterior) socket trianguloid 2= Left valve (posterior) socket channel-like notch 3= Left valve (posterior) socket groove-like 4= Left valve (posterior) socket ovoid 5= Left valve (posterior) socket V-shaped	1= No specimen associated 2= No specimen associated 3= No specimen associated 4= No specimen associated 5= See *Quadrula supenawensis*	0	0
54. Left valve (anterior) socket shape	1= Left valve (anterior) socket trianguloid 2= Left valve (anterior) socket channel-like notch 3= Left valve (anterior) socket ovoid	1= See S15387 2= See *Quadrula supenawensis* 3= No specimen associated	0	0
55. Left valve (posterior) socket depth	1= Left valve (posterior) socket with shallow depth 2= Left valve (posterior) socket with moderate depth 3= Left valve (posterior) socket with significant depth	1= No specimen associated 2= See *Quadrula supenawensis* 3= No specimen associated	0	0
56. Left valve (anterior) socket depth	1= Left valve (anterior) socket with shallow depth 2= Left valve (anterior) socket with moderate depth 3= Left valve (anterior) socket with significant depth	1= No specimen associated 2= See Quadrula supenawensis 3= No specimen associated	0	0
57. Left valve interdentum length	1= Interdentum shortest length 2= Interdentum of medium length 3= Interdentum of longest length	1= See *Plesielliptio danae* 2= See S15350 3= No specimen associated	1	0
58. Left valve with accessory dentacle (and pit in right valve)	0= Absent 1= Present 2= Not applicable	0= No specimen associated 1= No specimen associated 2= No specimen associated	0	0
59. Right valve cardinal number of teeth	0= Right valve cardinal number of teeth 0 1= Right valve cardinal number of teeth 1 2= Right valve cardinal number of teeth 2	0= No specimen associated 1= See *Quadrula primaevus* 2= See *Plesielliptio subspatulatus*	0.5	0
60. Right valve cardinal taphonomy/preservation	0= Right valve cardinal tooth taphonomy uninterpretable 1= Right valve cardinal tooth taphonomy poorly preserved 2= Right valve cardinal tooth taphonomy decently preserved 3= Right valve cardinal tooth taphonomy well preserved	0= No specimen associated 1= No specimen associated 2= *See Quadrula primaevus* 3= See S15508	1	0
61. Right valve cardinal (or single) tooth shape	0= Not applicable 1= Right valve cardinal tooth shape trianguloid/triangularly 2= Right valve cardinal tooth shape pyramidoid 3= Right valve cardinal tooth shape peg-like/conoid	0= No specimen associated 1= See *Plesielliptio subspatulatus* 2= See *Plesielliptio deweyanus* 3= See *Quadrula primaevus*	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
62. Right valve anterior cardinal tooth structure (grooves)	1= Simple 2= Moderate 3= Complex	1= See S15526 2= See *Plesielliptio subspatulatus* 3= See *Quadrula primaevus*	0.67	0.5
63. Right valve posterior cardinal (or single) tooth mass	1= Right valve posterior (or single) cardinal tooth mass delicate light 2= Right valve posterior (or single) cardinal tooth mass moderate 3= Right valve posterior (or single) cardinal tooth mass heavy	1= No specimen associated 2= See *Plesielliptio subspatulatus* 3= See *Quadrula primaevus*	0.67	0
64. Right valve cardinal tooth height	1= Right valve cardinal tooth least height 2= Right valve cardinal tooth moderate height 3= Right valve cardinal tooth greatest height	1= See S15508 2= See *Quadrula primaevus* 3= See *Plesielliptio deweyanus*	1	0
65. Right valve cardinal tooth orientation	1= Right valve cardinal tooth oriented oblique anterior 2= Right valve cardinal tooth oriented oblique posterior 3= Right valve cardinal tooth oriented vertical 4= Right valve cardinal tooth oriented parallel	1= See *Plesielliptio subspatulatus* 2= See *Plesielliptio deweyanus* 3= See *Quadrula primaevus* 4= See S15524	1	1
66. Right valve lateral tooth number	0= Right valve lateral teeth absent 1= Right valve lateral number of teeth 1 2= Right valve lateral number of teeth 2	0= No specimen associated 1= See *Quadrula primaevus* 2= No specimen associated	0	0
67. Right valve dorsal lateral tooth sculpture	0= Not applicable 1= Smooth 2= Serrated/sculptured	0= No specimen associated 1= See *Quadrula primaevus* 2= No specimen associated	1	0
68. Right valve lateral teeth strength	0= Right valve lateral teeth strength absent 1= Right valve lateral teeth strength weak 2= Right valve lateral teeth strength strong	0= No specimen associated 1= See *Quadrula primaevus* 2= No specimen associated	0	0
69. Right valve lateral teeth length	1= Right valve lateral teeth strength absent 2= Right valve lateral teeth length short 3= Right valve lateral teeth of medium length 4= Right valve lateral teeth length relatively long 5= Right valve lateral teeth length long	1= No specimen associated 2= No specimen associated 3= See *Quadrula primaevus* 4= No specimen associated 5= No specimen associated	1	0
70. Number of adductor muscle scars	0= Adductor muscle scar(s) unavailable to examine 1= One muscle scar 2= Two muscle scars	0= No specimen associated 1= See *Plesielliptio subspatulatus* 2= No specimen associated	0	0

Table 5. cont.

Character	States	References/Bins	CI	RI
71. Left valve anterior adductor muscle scar shape	0= Left valve anterior adductor muscle scar unavailable to examine 1= Left valve anterior adductor muscle scar shape elongate 2= Left valve anterior adductor muscle scar shape round 3= Left valve anterior adductor muscle scar shape 3	0= No specimen associated 1= No specimen associated 2= No specimen associated 3= No specimen associated	0	0
72. Left valve anterior adductor muscle scar size (dimension)	0= Left valve anterior adductor muscle scar unavailable to examine 1= Left valve anterior adductor muscle scar size small 2= Left valve anterior adductor muscle scar size medium 3= Left valve anterior adductor muscle scar size large	0= No specimen associated 1= No specimen associated 2= No specimen associated 3= No specimen associated	0	0
73. Left valve anterior adductor muscle scar strength/depth	0= Left valve anterior adductor muscle scar unavailable to examine/not applicable 1= Left valve anterior adductor muscle scar strength poorly developed/shallow to hardly present 2= Left valve anterior adductor muscle scar strength moderately developed/moderately deep 3= Left valve anterior adductor muscle scar strength strongly developed/deep	0= No specimen associated 1= No specimen associated 2= See *Plesielliptio subspatulatus* 3= No specimen associated	1	0
74. Left valve anterior adductor muscle scar internal structure/sculpture	0= Left valve anterior adductor muscle scar unavailable to examine/not applicable 1= Left valve anterior adductor muscle scar strength poorly developed/shallow to hardly present 2= Left valve anterior adductor muscle scar strength moderately developed/moderately deep 3= Left valve anterior adductor muscle scar strength strongly developed/deep	0= No specimen associated 1= See S15525 2= See *Plesielliptio subspatulatus* 3= No specimen associated	1	1
75. Left valve anterior adductor muscle scar undercut	0= Left valve anterior adductor muscle scar unavailable to examine/not applicable 1= Left valve anterior adductor muscle scar does not undercut hinge plate 2= Left valve anterior adductor muscle scar undercutting hinge plate	0= No specimen associated 1= See S15525 2= See *Quadrula supenawensis*	1	1
76. Left valve posterior adductor muscle scar size (dimension)	0= Left valve posterior adductor muscle scar unavailable to examine 1= Left valve posterior adductor muscle scar size small 2= Left valve posterior adductor muscle scar size medium 3= Left valve posterior adductor muscle scar size large	0= No specimen associated 1= See *Plesielliptio subspatulatus* 2= See *Quadrula supenawensis* 3= No specimen associated	0.5	0.5

Table 5. cont.

Character	States	References/Bins	CI	RI
77. Left valve posterior adductor muscle scar strength	0= Left valve posterior adductor muscle scar unavailable to examine 1= Left valve posterior adductor muscle scar strength poorly developed 2= Left valve posterior adductor muscle scar strength moderately developed 3= Left valve posterior adductor muscle scar strength strongly developed	0= No specimen associated 1= See *Plesielliptio subspatulatus* 2= See *Plesielliptio deweyanus* 3= See *Quadrula supenawensis*	1	0
78. Left valve posterior adductor muscle scar internal structure	0= Left valve posterior adductor muscle scar unavailable to examine 1= Left valve posterior adductor muscle scar internal structure with limited structure 2= Left valve posterior adductor muscle scar internal structure moderately divided 3= Left valve posterior adductor muscle scar internal structure strongly divided	0= No specimen associated 1= See *Quadrula supenawensis* 2= See *Plesielliptio subspatulatus* 3 No specimen associated	1	0
79. Right valve anterior adductor muscle scar strength/depth	0= Right valve anterior adductor muscle scar unavailable to examine/not applicable 1= Right valve anterior adductor muscle scar strength poorly developed/shallow, hardly present 2= Right valve anterior adductor muscle scar strength moderately developed/moderately deep 3= Right valve anterior adductor muscle scar strength strongly developed/deep	0= See *Plesielliptio deweyanus* 1= See S15525 2= See *Plesielliptio subspatulatus* 3= No specimen associated	1	0
80. Right valve anterior adductor muscle scar internal structure/sculpture	0= Right valve anterior adductor muscle scar unavailable to examine/not applicable 1= Right valve anterior adductor muscle scar internal structure with limited structure/smooth 2= Right valve anterior adductor muscle scar internal structure moderately divided/roughened 3= Right valve anterior adductor muscle scar internal structure strongly divided	0= *See Plesielliptio deweyanus* 1= See S15525 2= See *Plesielliptio subspatulatus* 3= No specimen associated	1	0
81. Right valve posterior adductor muscle scar size (dimension)	0= Right valve posterior adductor muscle scar unavailable to examine 1= Right valve posterior adductor muscle scar size small 2= Right valve posterior adductor muscle scar size medium 3= Right valve posterior adductor muscle scar size large	0= See *Plesielliptio deweyanus* 1= See *Plesielliptio subspatulatus* 2= No specimen associated 3= No specimen associated	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
82. Right valve anterior pedal protractor muscle scar size (dimension)	0= Right valve anterior pedal protractor muscle scar unavailable to examine 1= Right valve anterior pedal protractor muscle scar size small 2= Right valve anterior pedal protractor muscle scar size medium 3= Right valve anterior pedal protractor muscle scar size large	0= No specimen associated 1= See *Plesielliptio danae* 2= See *Plesielliptio subspatulatus* 3= No specimen associated	0.5	0.5
83. Right valve anterior pedal protractor muscle scar strength	0= Right valve anterior pedal protractor muscle scar unavailable to examine 1= Right valve anterior pedal protractor muscle scar strength poorly developed 2= Right valve anterior pedal protractor muscle scar strength moderately developed 3= Right valve anterior pedal protractor muscle scar strength strongly developed	0= No specimen associated 1= See S15493 2= See *Quadrula primaevus* 3= No specimen associated	1	1
84. Right valve anterior pedal protractor muscle scar internal structure	0= Right valve anterior pedal protractor muscle scar unavailable to examine 1= Right valve anterior pedal protractor muscle scar internal structure with limited structure 2= Right valve anterior pedal protractor muscle scar internal structure moderately divided 3= Right valve anterior pedal protractor muscle scar internal structure strongly divided	0= No specimen associated 1= See *Plesielliptio subspatulatus* 2= See *Plesielliptio deweyanus* 3= No specimen associated	0.5	0
85. Right Valve posterior pedal protractor muscle scar size (dimension)	0= Right valve posterior pedal protractor muscle scar unavailable to examine 1= Right valve posterior pedal protractor muscle scar size small 2= Right valve posterior pedal protractor muscle scar size medium 3= Right valve posterior pedal protractor muscle scar size large	0= See *Plesielliptio deweyanus* 1= See S15389 2= See *Plesielliptio danae* 3= No specimen associated	1	1
86. Right valve posterior pedal protractor muscle scar strength	0= Right valve posterior pedal protractor muscle scar unavailable to examine 1= Right valve posterior pedal protractor muscle scar strength poorly developed 2= Right valve posterior pedal protractor muscle scar strength moderately developed 3= Right valve posterior pedal protractor muscle scar strength strongly developed	0= See *Plesielliptio deweyanus* 1= See *Quadrula primaevus* 2= See *Plesielliptio deweyanus* 3= No specimen associated	1	0

Table 5. cont.

Character	States	References/Bins	CI	RI
87. Right valve posterior pedal protractor muscle scar internal structure	0= Right valve posterior pedal protractor muscle scar unavailable to examine 1= Right valve posterior pedal protractor muscle scar internal structure with limited structure 2= Right valve posterior pedal protractor muscle scar internal structure moderately divided 3= Right valve posterior pedal protractor muscle scar internal structure strongly divided	0= See *Plesielliptio deweyanus* 1= See *Quadrula primaevus* 2= See *Plesielliptio deweyanus* 3= No specimen associated	1	0
88. Pallial sinus development	1= Pallial line absent 2= Pallial line barely expressed/shallow 3= Pallial line readily expressed/deep	1= No specimen associated 2= See *Plesielliptio subspatulatus* 3= See *Quadrula primaevus*	0.33	0.6

Table 6. Data Matrix of type clam specimens. Question marks (?) mean no data available (As used in the MacClade (Maddison and Maddison, 2005) software).

Character	*Plesielliptio abbreviatus*	*Lampsilis consueta*	*Pleurobema cryptorhynchus*	*Corbicula cytheriformis*	*Plesielliptio danae*	*Plesielliptio deweyanus*	*Corbicula occidentalis*	*Sphaerium planum*	*Plesielliptio priscus*	*Anodonta propatoris*
1	2	2	2	1	2	2	1	0	2	2
2	1	1	1	2	0	?	2	2	0	2
3	?	?	?	2	2	?	2	?	?	?
4	3	3	4	2	4	3	2	1	3	4
5	2	2	1	2	2	2	1	2	2	1
6	2	2	2	2	5	2	1	2	1	2
7	2	2	2	2	2	2	2	2	2	2
8	2	2	?	2	2	2	2	2	3	2
9	2	2	2	1	2	2	1	1	2	2
10	4	?	2	1	1	1	?	1	2	?
11	6	?	0	0	0	0	0	0	1	?
12	1	?	?	0	?	?	?	?	1	?
13	2	?	?	?	1	1	1	1	2	?
14	4	?	?	1	1	1	1	1	4	?
15	4	?	3	3	3	3	4	3	3	5
16	3	3	2	3	2	1	3	3	2	3
17	1	?	1	1	1	1	1	1	1	?
18	4	?	1	4	1	4	1	1	4	?
19	2	2	5	6	5	5	6	5	6	?
20	3	?	0	0	0	3	0	0	1	?
21	2	?	0	0	0	2	0	0	2	?
22	0	?	0	0	0	0	0	0	0	?
23	3	3	3	3	2	2	1	1	1	1

Table 6. cont.

Character	*Plesielliptio abbreviatus*	*Lampsilis consueta*	*Pleurobema cryptorhynchus*	*Corbicula cytheriformis*	*Plesielliptio danae*	*Plesielliptio deweyanus*	*Corbicula occidentalis*	*Sphaerium planum*	*Plesielliptio priscus*	*Anodonta propatoris*
24	2	?	1	1	1	1	1	1	1	1
25	1	?	2	0	1	1	?	1	2	?
26	2	?	2	2	1	1	1	1	1	1
27	2	?	1	1	1	1	1	1	2	1
28	1	?	1	1	1	1	1	1	1	1
29	1	?	1	1	2	2	1	1	2	2
30	?	?	?	1	?	?	1	?	?	?
31	?	?	?	1	?	?	1	?	?	?
32	1	?	2	?	1	1	?	?	?	?
33	?	?	3	?	2	1	?	?	?	?
34	?	?	3	?	3	3	?	?	?	?
35	?	?	1	?	3	2	?	?	?	?
36	?	?	2	?	2	1	?	?	?	?
37	2	?	2	2	0	3	?	?	?	?
38	2	?	1	?	2	2	?	?	?	?
39	2	?	1	?	2	2	?	?	?	?
40	3	?	3	?	2	3	?	?	?	?
41	2	?	1	?	1	2	?	?	?	?
42	2	?	2	?	2	2	?	?	?	?
43	3	?	3	?	3	3	?	?	?	?
44	1	?	4	?	1	4	?	?	?	?
45	3	?	2	?	2	2	?	?	?	?
46	2	?	1	?	1	1	?	?	?	?

Table 6. cont.

Character	*Plesielliptio abbreviatus*	*Lampsilis consueta*	*Pleurobema cryptorhynchus*	*Corbicula cytheriformis*	*Plesielliptio danae*	*Plesielliptio deweyanus*	*Corbicula occidentalis*	*Sphaerium planum*	*Plesielliptio priscus*	*Anodonta propatoris*
47	2	?	1	?	2	2	?	?	?	?
48	3	?	3	?	3	3	?	?	?	?
49	1	?	3	?	1	3	?	?	?	?
50	?	?	0	?	?	?	?	?	?	?
51	?	?	0	?	?	?	?	?	?	?
52	?	?	0	?	?	?	?	?	?	?
53	?	?	0	?	?	?	?	?	?	?
54	?	?	?	?	?	?	?	?	?	?
55	?	?	?	?	?	?	?	?	?	?
56	?	?	?	?	?	?	?	?	?	?
57	?	?	?	?	?	?	?	?	?	?
58	?	?	?	?	1	1	?	?	?	?
59	?	?	?	?	?	?	?	?	?	?
60	?	?	2	?	?	1	?	?	?	?
61	?	?	2	?	?	2	?	?	?	?
62	?	?	3	?	?	2	?	?	?	?
63	?	?	2	?	?	3	?	?	?	?
64	?	?	2	?	?	3	?	?	?	?
65	?	?	2	?	?	3	?	?	?	?
66	?	?	3	?	?	2	?	?	?	?
67	?	?	?	?	?	1	?	?	?	?
68	?	?	?	?	?	2	?	?	?	?
69	?	?	?	?	?	1	?	?	?	?

Table 6. cont.

Character	*Plesielliptio abbreviatus*	*Lampsilis consueta*	*Pleurobema cryptorhynchus*	*Corbicula cytheriformis*	*Plesielliptio danae*	*Plesielliptio deweyanus*	*Corbicula occidentalis*	*Sphaerium planum*	*Plesielliptio priscus*	*Anodonta propatoris*
70	?	?	?	?	?	1	?	?	?	?
71	?	?	?	?	?	1	?	?	?	?
72	?	?	?	?	?	2	?	?	?	?
73	?	?	?	?	?	2	?	?	?	?
74	?	?	?	?	2	1	?	?	?	?
75	2	?	?	?	?	2	?	?	?	?
76	2	?	?	?	?	2	?	?	?	?
77	2	?	?	?	?	2	?	?	?	?
78	0	?	?	?	?	2	?	?	?	?
79	1	?	?	?	?	1	?	?	?	?
80	?	?	?	?	?	0	?	?	?	?
81	?	?	?	?	?	0	?	?	?	?
82	?	?	?	?	?	0	?	?	?	?
83	?	?	?	?	1	2	?	?	?	?
84	?	?	?	?	2	2	?	?	?	?
85	?	?	?	?	1	2	?	?	?	?
86	?	?	?	?	2	0	?	?	?	?
87	?	?	?	?	2	0	?	?	?	?
88	3	?	?	?	3	?	2	?	?	?

Table 6. cont.

Character	*Plesielliptio subspatulatus*	*Quadrula supenawensis*	*Sphaerium subellipticum*	*Quadrula primaevus*	*Corbula undifera*	*Corbula subtrigonalis*	*Rhabdotophorus senectus*	*Plesielliptio stantoni*	*Sphaerium recticardinale*
1	2	2	0	2	1	1	2	2	0
2	0	?	1	?	2	2	0	0	1
3	2	?	?	?	?	?	?	?	?
4	3	2	3	2	8	5	4	3	9
5	2	2	2	2	4	4	2	2	2
6	2	2	2	2	2	2	1	2	2
7	2	2	2	2	2	2	2	2	2
8	3	2	2	2	3	4	2	2	2
9	2	2	2	2	1	1	2	2	1
10	4	5	?	1	4	1	?	4	1
11	1	0	0	0	0	0	0	0	0
12	1	?	?	?	?	?	?	?	?
13	2	1	1	1	1	1	1	1	1
14	4	1	1	1	1	1	1	1	1
15	2	5	?	3	3	4	?	2	1
16	1	1	3	2	3	3	1	1	2
17	1	1	1	1	1	1	1	1	1
18	4	1	1	1	1	1	1	?	1
19	6	4	1	5	5	5	5	6	6
20	3	0	0	0	0	0	0	0	0
21	2	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0
23	1	4	1	1	4	3	1	4	2

Table 6. cont.

Character	*Plesielliptio subspatulatus*	*Quadrula supenawensis*	*Sphaerium subellipticum*	*Quadrula primaevus*	*Corbula undifera*	*Corbula subtrigonalis*	*Rhabdotophorus senectus*	*Plesielliptio stantoni*	*Sphaerium recticardinale*
24	1	1	1	1	2	2	1	2	2
25	2	2	?	2	?	1	?	2	1
26	?	1	?	1	1	1	1	1	1
27	?	1	?	1	1	1	1	1	1
28	?	?	?	1	1	1	1	1	1
29	?	?	?	1	1	1	2	2	1
30	?	?	?	?	?	?	?	?	?
31	?	?	?	?	?	?	?	?	?
32	1	2	?	2	?	?	?	?	?
33	2	3	?	2	?	?	?	?	?
34	2	3	?	2	?	?	2	?	?
35	2	3	?	2	?	?	2	?	?
36	2	4	?	2	?	?	1	?	?
37	2	2	?	2	?	?	?	?	?
38	2	2	?	?	?	?	?	?	?
39	2	2	?	?	?	?	?	?	?
40	2	2	?	?	?	?	?	?	?
41	2	2	?	?	?	?	?	?	?
42	2	2	?	?	?	?	?	?	?
43	3	3	?	?	?	?	?	?	?
44	4	4	?	?	?	?	?	?	?
45	2	1	?	?	?	?	?	?	?
46	2	1	?	?	?	?	?	?	?

Table 6. cont.

Character	*Plesielliptio subspatulatus*	*Quadrula supenawensis*	*Sphaerium subellipticum*	*Quadrula primaevus*	*Corbula undifera*	*Corbula subtrigonalis*	*Rhabdotophorus senectus*	*Plesielliptio stantoni*	*Sphaerium recticardinale*
47	2	2	?	?	?	?	?	?	?
48	3	3	?	?	?	?	?	?	?
49	4	1	?	?	?	?	?	?	?
50	2	2	?	?	?	?	?	?	?
51	2	2	?	?	?	?	?	?	?
52	3	4	?	?	?	?	?	?	?
53	1	2	?	?	?	?	?	?	?
54	?	5	?	?	?	?	?	?	?
55	?	2	?	?	?	?	?	?	?
56	?	2	?	?	?	?	?	?	?
57	?	2	?	?	?	?	?	?	?
58	2	1	?	?	?	?	?	?	?
59	?	?	?	?	?	?	?	?	?
60	2	?	?	1	?	?	?	?	?
61	2	?	?	2	?	?	?	?	?
62	1	?	?	3	?	?	?	?	?
63	2	?	?	3	?	?	?	?	?
64	2	?	?	3	?	?	?	?	?
65	2	?	?	2	?	?	?	?	?
66	1	?	?	3	?	?	?	?	?
67	1	?	?	1	?	?	1	?	?
68	1	?	?	1	?	?	1	?	?
69	1	?	?	1	?	?	1	?	?

Table 6. cont.

Character	*Plesielliptio subspatulatus*	*Quadrula supenawensis*	*Sphaerium subellipticum*	*Quadrula primaevus*	*Corbula undifera*	*Corbula subtrigonalis*	*Rhabdotophorus senectus*	*Plesielliptio stantoni*	*Sphaerium recticardinale*
70	1	?	?	1	?	?	1	?	?
71	3	?	?	3	?	?	2	?	?
72	1	?	?	1	?	?	1	?	?
73	?	?	?	?	?	?	?	?	?
74	?	?	?	?	?	?	?	?	?
75	2	?	?	2	?	?	?	?	?
76	2	2	?	?	?	?	?	?	?
77	2	2	?	?	?	?	?	?	?
78	1	2	?	?	?	?	?	?	?
79	1	3	?	?	?	?	?	?	?
80	2	1	?	?	?	?	?	?	?
81	2	?	?	?	?	?	?	?	?
82	2	?	?	?	?	?	?	?	?
83	1	?	?	?	?	?	?	?	?
84	2	?	?	2	?	?	?	?	?
85	2	?	?	2	?	?	?	?	?
86	1	?	?	2	?	?	?	?	?
87	?	?	?	2	?	?	?	?	?
88	2	3	?	3	?	?	3	?	?

Table 7. Data matrix of type snail specimens. Question marks (?) mean no data available (as used in the MacClade (Maddison and Maddison, 2005) software).

Character	*Campeloma vetulum*	*Lioplacodes praecursa*	*“Hydrobia” subconica*	*“Hydrobia” recta "USNM 29856a & b subcylindrica"*	*Aplexa atavus*	*Melanoides convexa*	*Melanoides convexa impressa*	*Physa copei*	*Lioplacodes invenusta*	*Lioplacodes judithensis*	*Viviparus montanaensis*	*Vitrina obliqua*
1	1	1	0	0	2	1	1	2	1	1	1	2
2	1	1	0	2	1	2	1	0	1	2	0	0
3	1	0	1	0	0	0	2	1	0	1	2	2
4	1	0	1	1	1	?	1	?	1	?	?	?
5	0	1	1	1	1	1	1	1	1	0	0	0
6	?	?	?	?	?	?	?	?	?	?	0	0
7	3	2	3	1	1	0	0	5	3	2	7	3
8	?	?	?	?	?	?	?	?	?	?	?	?
9	1	1	1	0	0	0	0	1	0	?	?	?
10	2	2	3	2	3	3	3	0	2	2	0	0
11	0	1	0	2	0	2	2	0	2	2	0	0
12	2	0	1	0	0	0	0	1	0	?	?	?
13	2	1	0	1	1	0	1	2	1	3	2	1
14	0	0	0	0	0	0	0	0	0	0	1	0
15	0	0	1	?	?	?	?	0	0	?	?	1
16	2	2	0	2	0	0	1	1	1	3	3	2
17	0	0	0	0	0	0	0	0	0	0	0	?
18	0	0	0	0	0	1	1	0	0	1	0	?
19	0	0	0	0	0	0	0	0	0	1	0	?
20	0	0	0	0	0	0	1	0	0	0	0	?
21	0	0	0	0	0	0	0	0	0	0	0	?
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	1	1	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	1	1	1	?	0	1	1	?	1	1	?	1
26	1	2	2	?	?	2	?	?	2	?	?	?

Table 7. cont.

Character	*Campeloma vetulum*	*Lioplacodes praecursa*	*“Hydrobia” subconica*	*“Hydrobia” recta "USNM 29856a & b subcylindrica"*	*Aplexa atavus*	*Melanoides convexa*	*Melanoides convexa impressa*	*Physa copei*	*Lioplacodes invenusta*	*Lioplacodes judithensis*	*Viviparus montanaensis*	*Vitrina obliqua*
27	2	?	?	?	0	0	0	?	0	?	?	?
28	2	2	?	?	?	?	?	?	0	?	?	?
29	1	?	?	?	?	?	?	?	2	?	?	?
30	1	?	?	?	?	?	1	0	2	?	?	?
31	2	0	0	1	1	0	0	1	1	1	2	2
32	0	0	0	0	0	1	1	0	0	0	0	0
33	0	0	0	0	0	2	2	0	0	0	0	0
34	0	0	0	0	1	0	0	1	0	0	0	0

Table 7. cont.

Character	*“Helix” occidentalis*	*Campeloma vetula pegmate*	*Physa subelongata*	*Melanoides sublaevis*	*Lioplacodes subtortuosa*	*Lioplacodes gracilenta*	*Viviparus conradi*	*Physa canadensis tenuis*	*Viviparus nidaga*	*Melanoides omitta*
1	1	1	0	0	2	1	1	2	1	1
2	1	1	0	2	1	2	1	0	1	2
3	1	0	1	0	0	0	2	1	0	1
4	1	0	1	1	1	?	1	?	1	?
5	0	1	1	1	1	1	1	1	1	0
6	?	?	?	?	?	?	?	?	?	?
7	3	2	3	1	1	0	0	5	3	2
8	?	?	?	?	?	?	?	?	?	?
9	1	1	1	0	0	0	0	1	0	?
10	2	2	3	2	3	3	3	0	2	2
11	0	1	0	2	0	2	2	0	2	2
12	2	0	1	0	0	0	0	1	0	?

Table 7. cont.

Character	*"Helix" occidentalis*	*Campeloma vetula pegmate*	*Physa subelongata*	*Melanoides sublaevis*	*Lioplacodes subtortuosa*	*Lioplacodes gracilenta*	*Viviparus conradi*	*Physa canadensis tenuis*	*Viviparus nidaga*	*Melanoides omitta*
13	2	1	0	1	1	0	1	2	1	3
14	1	0	1	1	0	0	0	0	0	0
15	0	0	?	0	1	0	0	2	0	1
16	2	2	0	2	3	2	0	1	2	1
17	0	0	0	1	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	?	0	?	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	1	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0
25	2	1	2	1	1	?	1	1	1	1
26	2	2	?	2	2	2	0	1	0	2
27	0	2	?	0	2	?	0	?	0	0
28	2	2	?	0	2	1	?	2	0	?
29	2	1	?	0	?	?	?	?	2	1
30	2	1	?	0	1	?	?	0	1	1
31	2	1	1	0	1	0	?	1	2	0
32	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0
34	0	0	1	0	0	0	0	1	0	0

RESULTS

Two majority-rule consensus trees were used to summarize phylogenetic trees constructed via PAUP* (Swofford, 2002) for bivalves and gastropods (Figs. 6, 7). The snail majority-rule consensus tree was created using 149,165 trees compromised of 56 specimens. Twenty-eight of 34 traits were considered informative. Three traits were constant, meaning they did not change across all specimens. Three traits were parsimony uninformative, meaning they had a significant amount of missing data or were unique to particular individual taxa. Overall, the tree's score was 193, meaning the most parsimonious tree had 193 steps or character state changes across the phylogeny.

The clam majority-rule consensus tree was comprised of 91,700 trees made up of 72 specimens. Fifty-one of 88 traits were considered useful. Fifteen traits were constants, and 22 were parsimony uninformative or had a significant amount of missing data. Overall, the trees score was 197, which means the most parsimonious tree had 197 steps or character state changes across the phylogeny.

The creation of the majority-rule consensus trees provides a framework for this study, allowing consistent species diagnoses. With a more confidently identified population of collected specimens, future work can focus on population and ecology studies like the examples presented below. Presented here is an enumerated list of these conclusions for ease of reference.

1. Utilize preliminary analysis of Judith River Formation taxa for analytical species diagnosis of molluscan fauna of the Upper Cretaceous. The methodology used is not new but has never been used on species identified here. The hypothesis is that this methodology will provide a more accurate way to identify species in the Judith River Formation.

2. This study helps to identify some of the weaknesses in the Judith River Formation type specimen preservation and identification. Many of the type specimens are incomplete or fragmentary making analytical identifications difficult or impossible.
3. The study has helped identify certain traits that are useful or not useful in identification of Judith River Formation mollusks. Certain traits, such as symmetry of the shell and the shells height to length ratio did not appear to be useful for identification of clams in the Judith River Formation. Traits such as inclusion or lack of sculpture and beak placement proved to be very important in identifying clam species, while shell height and aperture shape proved to be useful in snail diagnosis.
4. This study helped identify, on a narrower scale, distribution of environments at important localities of the Judith River Formation. Generalized depositional environments in the Judith River Formation is known previous work (Rogers, 1994, 1998; Rogers et al., 2016), but this study looks at a finer scale describing individual locality depositional environments based on local fauna.

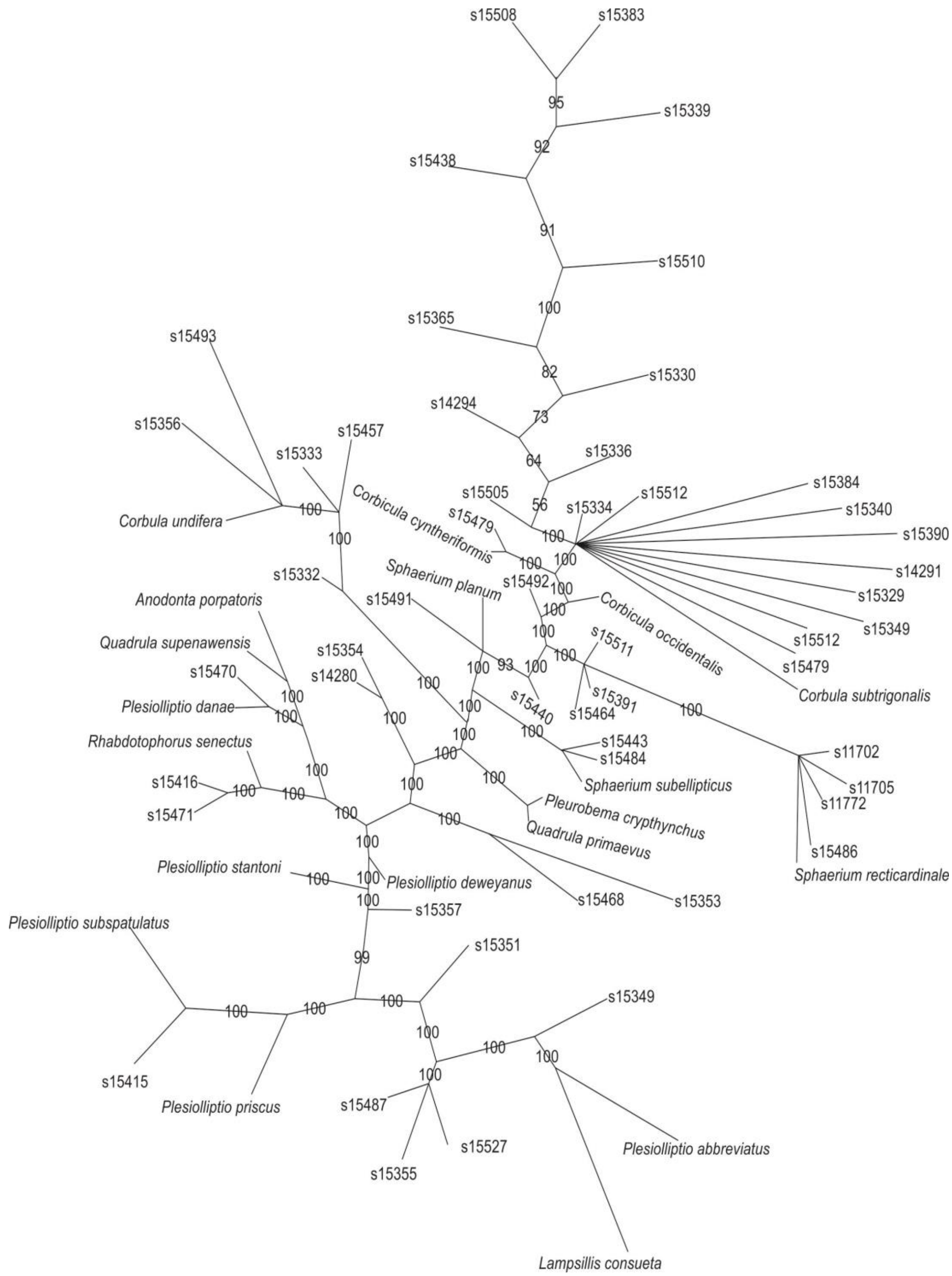


Figure 6. Unrooted Majority-Rule Consensus Tree made using PAUP* (Swofford, 2002) for clam specimens. Numbers between nodes indicate the percent of created trees that replicated this grouping. Length is 197 steps, CI = 0.57, RI = 0.82.

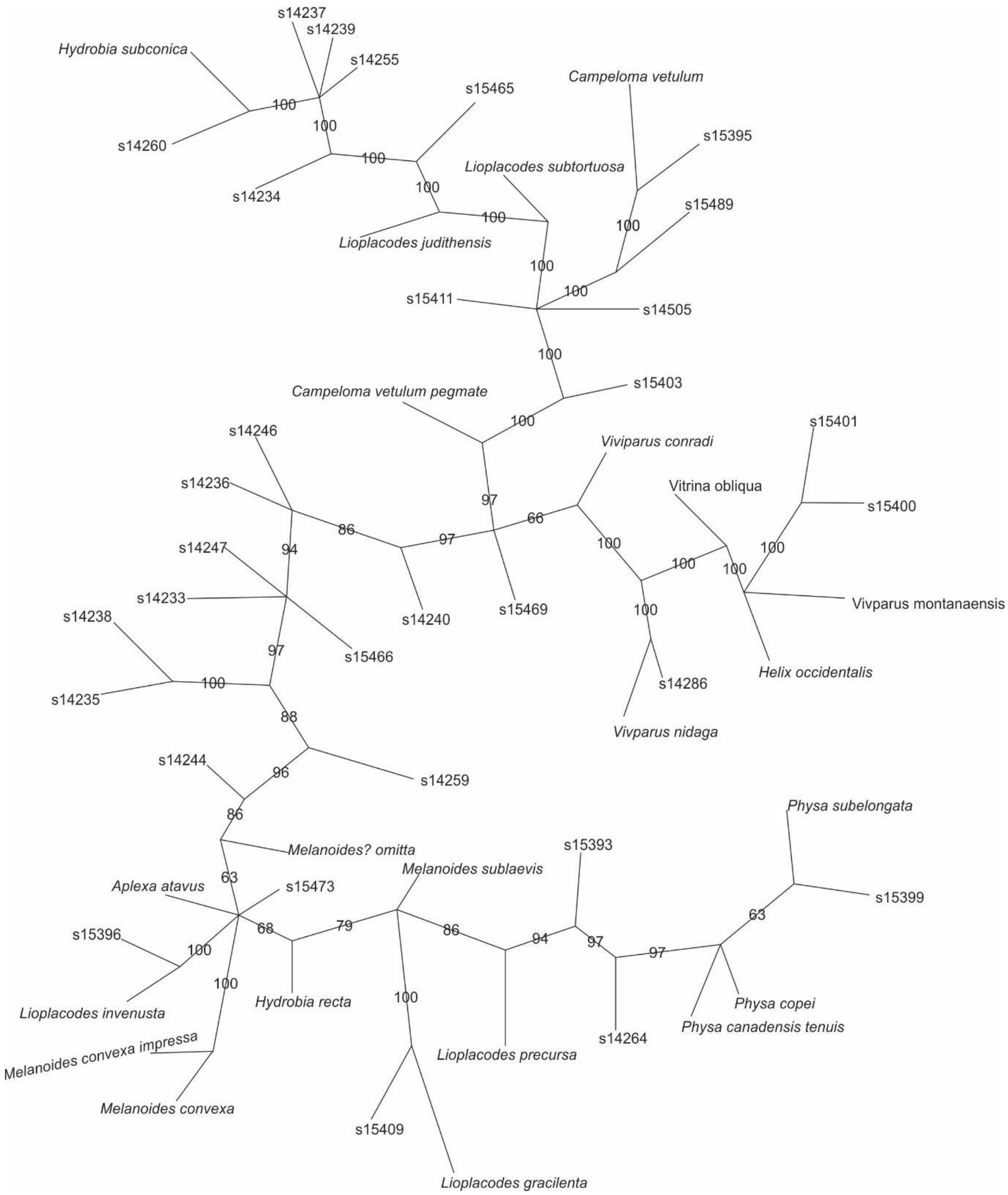


Figure 7. Unrooted Majority-Rule Consensus Tree made using PAUP* (Swofford, 2002) for snail specimens. Numbers between nodes indicate the percent of created trees that replicated this grouping. Length is 193 steps, CI = 0.33, RI = 0.67.

Discussion

The following discussion diagnoses individual specimens from the Judith River Formation as part of an explanation of clustering association of species on the resulting consensus tree. Where possible, shell features are discussed in the following order: 1. Shell shape, 2. Margins, 3. Sculpture, 4. Umbo elevation, 5. Beaks, 6. Shell size, and 7. Growth line development. Confidence of placement is based on the majority-rule consensus tree (Fig 6), where in percentage reported represents the percentage in which the number of created trees placed specimens as sister taxa.

Specimen L7379, S15391.

Specimen S15391 clustered with *Sphaerium recticardinale* on the majority-rule consensus tree with 100% confidence. Similar features include rectilinear shape, slightly elevated umbo, very anteriorly pointed beaks, and growth lines of varying strength.

Specimen S15391 is similar to *Sphaerium rectic*ardinale in its rectilinear shape, but it is slightly more rounded in the posterior and anterior margins than type specimens (USNM 2129a, b, c, d) of *S. recticardinale*. Specimen S15391 is distinct from *Sphaerium planum* as *S. planum* is similar to *S. recticardinale* in size and shape. Specimen S15391 is smaller in length than the types at 4.46 mm, while the type series ranges from 14.65 mm to 14.74 mm for a complete shell. This could mean the shell is a sub-adult.

Specimen s15464 differs in having more rounded posterior and anterior margins, in addition to lacking variation in growth lines. Specimen S15464 is smaller than the type series (6.19 mm in length, while the types range from 14.65 mm to 14.74 mm).

Specimen L7378, S15479.

Specimen S15479 was placed with *Corbula subtrigonalis* in the consensus tree with 100% confidence. Similarities include the triangular shape of the disc, size (13.52 mm in length, types range from 10.4 mm to 24.47 mm), the convex posterior and anterior margins and varying growth lines.

Specimen L7378, S15487.

Specimen S15487 was placed with *Lampsilis consueta* in the majority-rule consensus tree with 50% confidence. Similarities include elongate shell shape, broad convexity of the posterior and anterior margins, less prominent umbo, slight convexity of the shell, and broad umbo.

Differences are size (74.06 mm in length, types range from 54.25 mm to 57.33 mm), and preservation of *Plesielliptio*-like sculpture. Sculpture preservation is a problem; the types of *L. consueta* (USNM 29699a, b, c) do not preserve umbonal sculpture, though preservation is poor in that region of all the type shells. *Plesielliptio stantoni* (USNM 358004) seems like another likely placement for S15487 as it shares a broad umbo, elongate shape, broadly convex posterior and anterior margins and *Plesielliptio*-like sculpture.

Specimen L6927c, S11702.

Specimen S11702 was placed with *Sphaerium recticardinale* on the majority-rule consensus tree with 100% confidence. Similarities include rectangular shell shape, pronounced umbo, a slight posterior ridge, size (9.43 mm in length, the types range from 14.65 mm to 14.74 mm) and varied growth line strength.

Differences include more convex posterior and anterior margins than the types (USNM 2129a, b, c, d) and more centrally placed beak, which are traits known to *S. planum.*

Specimen L6927c, S11705.

Specimen S11705 was placed with *Sphaerium recticardinale* in the majority-rule consensus tree with 100% confidence. Similarities include rectangular shape, pronounced umbo, robust posterior ridge, size (10.84 mm in length, types range from 14.65 mm to 14.74 mm) and varied growth line strength.

Differences include more convex posterior and anterior margins than the types (USNM 2129a, b, c, d) and beaks placed centrally on the margin, traits known to *Sphaerium planum.*

Specimen L6927c, S11772.

Specimen S11772 was also placed with *Sphaerium recticardinale* in the majority-rule consensus tree with 100% confidence. Similarities include rectangular shape of the shell, convex posterior and anterior margins, pronounced posterior ridge and umbo, anteriorly placed beak and size (21.08 mm in length, types ranging from 14.65 mm to 14.74 mm). Though the specimen is slightly larger than the range, it is not so big to justify another placement.

Specimen L6927a, S15486.

Specimen S15486 was placed with *Sphaerium recticardinale* in the majority-rule consensus tree with 100% confidence. Similarities include rectangular shaped shell, convex posterior and anterior margins, pronounced umbo and posterior ridge, anterior placement of the beaks on the dorsum, size (9.72 mm in length, types range from 14.65 mm to 14.74 mm) and growth lines that are varied with stronger lines near margins.

The umbo is less pronounced than in the type series specimens (USNM 2129a, b, c, d) though not significantly; this could be because of interspecies variation.

Specimen L6927a, S15484.

Specimen S15484 was placed with *Sphaerium subellipticum* on the majority-rule consensus tree with 100% confidence. Similarities include elongate shell shape, broadly convex posterior and anterior margins, centrally placed umbo that is slightly raised on dorsum, and growth lines of varied strength.

Size (21.6 mm in length, types range from 6.16 mm to 6.93 mm for incomplete shells) is a prominent difference, though none of the types are complete (USNM 2128, 2128a). Shell also shows a slightly prominent posterior ridge, which is not seen on *Sphaerium subellipticum* types and resembles *Sphaerium recticardinale.*

Specimen L7380, S15492.

Specimen S15492 was placed near *Corbicula occidentalis* in the majority-rule consensus tree with 50% confidence. It is elongate is shape but in the dorsal-ventral position. It has long posterior and anterior margins, where the dorsal margin has an abrupt curvature change. Shell shows minimal convexity and is quite flat. Umbo is not very raised but is prominent. No internal view is preserved and so no dentition can be used for diagnostics. This specimen is unlike any of the types measured. The current hypothesis is that this specimen in a part of the genus *Ostrea*.

Specimen L7380, S15491.

Specimen S15491 was placed with *Sphaerium planum* in the majority-rule consensus tree with 100% confidence. Similarities include circular shell shape, lack of shell convexity, stratified growth line strength, with stronger lines near margins, low and centrally placed umbo, and lack of change in curvature across the shell.

Specimen S15491 differs from the types of *Sphaerium planum* (USNM 2130, a, b) by size (4.1 mm in length, the types range from 8.12 mm to 14.36 mm) though this is likely a sub-adult shell.

Specimen L7224, S15440.

Specimen S15440 was placed near *Sphaerium planum* in the majority-rule consensus tree with 93% confidence. Similarities include the circular shell shape, the convex posterior and anterior margins, the flatness of the shell, the low, centrally placed beaks, size (6.55 mm in length, types range from 8.12 mm to 14.36 mm) though this is likely a sub-adult shell, and the varied growth line strength (with the stronger lines near the margins).

Specimen L7224, S15511.

Specimen S15511 clustered with *Sphaerium recticardinale* on the majority-rule consensus tree with 100% confidence. Similar features include rectilinear shape, anteriorly placed beaks, size, and preserves varying growth line development.

Dorsal and ventral margins of specimen S15511 are broadly convex. Umbo is less pronounced than specimens of the type series, but it still more pronounced than that seen in *Sphaerium planum* (USNM 2130). Specimen S15511 is 8.05 mm in length, which is smaller than the type series (USNM 2129a, b, c, d), which range from 14.65 mm to 14.74 mm for a complete shell. The specimen may differ by preserving a pattern of thin lines near the umbo and thicker growth lines about halfway down the disk to the margins.

Specimen L7224, S15527.

Specimen S15527 was placed with *Lampsilis consueta* on the consensus tree with 50% confidence. Similar features include the ovate shell shape, the ventral and dorsal margins' broad convexity, the lack of sculpture (though this could be due to preservation), the anterior (but not terminal) position of the umbo and beak on the dorsum, and the varied growth line pattern.

Unfortunately, not having decent umbo preservation makes diagnosing this specimen difficult and it shares many of the previous traits with *Rhabdotophorus senectus*, and *Plesielliptio stantoni*. Sculpture seems to be significant in diagnosing species in large unionid clams, and having preservation issues related to the umbo and sculpture is difficult to overcome.

Specimen L7224, S15510.

Specimen S15510 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shape, convex ventral margin and angular dorsal margin, thin convexity of the shell, lack of sculpture, pronounced growth lines near the margins, pronounced posterior ridge, raised beaks placed slightly anteriorly of the center of the dorsum and size (16.05 mm in length, with types ranging from 10.4 mm to 24.47 mm).

Specimen L7224, S15512.

Specimen S15512 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shape, convex ventral margin and angular dorsal margin, thin convexity of the shell, lack of sculpture, pronounced growth lines near the margins, pronounced posterior ridge, raised beaks placed slightly anteriorly of the center of the dorsum and size (22.19 mm in length, with types ranging from 10.4 mm to 24.47 mm).

Specimen L7224, S15443.

Specimen S15443 was placed with *Sphaerium subellipticum* on the majority-rule consensus tree with 100% confidence. Similarities include elongate shape, broadly convex dorsal and ventral margins, low placed beaks, centrally placed umbo.

Much of the shell is missing, but size is different (16.04 mm in length, types range from 6.16 mm to 6.93 mm). Growth lines are missing because of preservation issues as well. This assignment is difficult due to preservation of the specimen. Lacking shell material and shell compression weaken the assignment, though size and elongate shape do provide a somewhat definitive basis for assignment.

Specimen L7224, S15457.

Specimen S15457 was placed with *Corbula undifera* in the majority-rule consensus tree with 100% confidence. Similarities include triangular shell shape, marked curvature change on dorsal margin, broadly convex ventral margin, a marked curvature change on the posterior margin in almost a "flaring" structure, a raised umbo, beaks placed anteriorly on the dorsum, and varied strong growth lines that are diagnostic of *C. undifera* (USNM 9060).

Specimen L7224, S15349.

Specimen S15349 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similarities include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, thinness of the shell, lack of sculpture, slightly anteriorly placed beaks, size (11.2 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines that are varied in prominence.

Specimen L7224, S15438.

Specimen S15438 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a not very convex shell, lack of sculpture, a strong posterior ridge, a slightly anterior beak placement, size (18.53 mm in length, type specimens range from 10.4 mm to 24.47 mm), and varied growth line strength.

Specimen L4618, S15332.

Specimen S15332 is placed with *Corbula undifera* in the majority-rule consensus tree with 100% confidence. Similar features include a pronounced umbo and size (18.69 mm in length, type specimens range from 16.25 mm to 30.39 mm). Likely, many of this specimen's traits are ambiguous between sections, causing it to match with traits that could be objective.

Specimen S15332 differs from *Corbula undifera* in that the shell is more elongate than the type specimen (USNM 9060) instead of triangular, it lacks varied pronounced growth lines seen in USNM 9060, and it lacks the marked change in the posterior margin.

Specimen L4618, S15330.

Specimen S15330 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular to trapezoidal shape, a convex ventral margin, angular dorsal margin, a marked curvature change in the posterior margin, a lack of convexity in the shell, lack of sculpture, a slightly anterior beak placement on the dorsum, size (23.64 mm in length, type specimens range from 10.4 mm to 24.47 mm) and growth lines with varied prominence.

Specimen L4618, S15329.

Specimen S15329 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include a triangular shape, a convex ventral margin, angular dorsal margin, lack of sculpture, and anterior placement of the beaks.

Differences are a marked curvature change on the posterior margin, a trait commonly seen in *Corbula undifera* (USNM 9060). The shell is also very convex in shape, thicker than types of *Corbula subtrigonalis,* looking more like types of *C. undifera.* Growth lines of varying prominence resemble *C. undifera* as well. The shell is also 27.45 mm in length, which is larger than types of *C. subtrigonalis* (10.4 mm to 24.47 mm) and closer to *C. undifera* (16.25 mm to 30.39 mm). Beaks are also raised high on the dorsum, more like *C. undifera.*

Specimen L4562, S15333.

Specimen S15333 was placed with *Corbula undifera* in the majority-rule consensus tree with 100% confidence. Similar features include a triangular to trapezoidal shape, a broadly convex anterior margin, an abrupt curvature change in the posterior margin, a raised umbo, a slightly anteriorly placed beak, size (31.27 mm in length, types range from 16.25 mm to 30.39 mm), and growth lines that vary in strength.

Specimen L4620, S15358.

Specimen S15358 was placed with *Corbula undifera* in the majority-rule consensus tree with 100% confidence. Similar traits include triangular shape, a convex anterior margin, a marked curvature change on the posterior margin, exhibits varied growth line strength covering the shell and a prominent posterior ridge.

The shell differs slightly in size (10.09 mm in length, types range from 16.25 mm to 30.39 mm). This is a marked difference, but considering all the similarities, this likely means the shell is a sub-adult.

Specimen L7225, S15493.

Specimen S15493 was placed with *Corbula undifera* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a broadly convex ventral margin, an angular dorsal margin, a posterior margin with a marked curvature change, a pronounced posterior ridge, raised umbo, anteriorly placed beaks, size (21.24 mm in length, types range from 16.25 mm to 30.39 mm), and growth lines that vary in strength that resemble sculpture.

Specimen L7225, S15508.

Specimen S15508 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include a triangular shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, convex anterior margin, lacks sculpture, slightly raised anteriorly placed beaks, a pronounced posterior ridge, size (14.33 mm in length, types range from 16.25 mm to 30.39 mm), and varied growth line strength.

Specimen L7225, S15505.

Specimen S15505 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (22.22 mm in length, types range from 10.4 mm to 24.47 mm), and varied growth lines.

Specimen L7300, S14280.

Specimen S14280 was not closely associated with any species. One of the nearest assignments is *Plesielliptio stantoni*, which could be the right classification. Similar features include an ovate shell shape, convex dorsal and ventral margins, broadly convex posterior and anterior margins, moderate shell convexity, a slightly pronounced umbo, and *Plesielliptio*-like sculpture.

Shell shape suggests a *Lampsilis consueta* assignment, though lack of preserved sculpture in on type specimens of *L. consueta* suggests a different assignment. Umbo shape is interesting as well, as it is different from any of *Plesielliptio* type specimens, as sculpture seems to suggest would be a good classification.

Specimen L7300, S14291.

Specimen S14291 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, and raised beaks placed anteriorly on the dorsum.

Shell is 32.41 mm in length, types range from 10.4 mm to 24.47 mm, which is larger than figured types. This could be an exceptionally large specimen as is shares many traits with *Corbula subtrigonalis*, though size is similar to *Corbula undifera*.

Specimen L7300, S14294.

Specimen S14294 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, and growth lines stronger near margins.

Shell is 32.66 mm in length, types range from 10.4 mm to 24.47 mm, which is larger than figured types. Like specimen S14291, this could be an exceptionally large specimen as it shares many traits with *Corbula subtrigonalis*, though size is similar to *Corbula undifera*.

Specimen L4617, S15354.

Specimen S15354 was not placed with any specific species. It is not distant from *Plesielliptio stantoni* to which it probably belongs. Similar features are elongate shell shape, broadly convex ventral and dorsal margins, *Plesielliptio*-like sculpture on the beak, not much raised umbo that is broad, a pronounced posterior ridge, size (85.39 mm in length, USNM 358004 is 81.56 mm), and thick growth lines near the umbo.

Specimen L4617, S15390.

Specimen S15390 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, and growth lines stronger near margins.

Shell is 30.79 mm in length, while types range from 10.4 mm to 24.47 mm. This is larger than the types, but because specimen S15390 shares so many traits with figured specimens of *Corbula subtrigonalis* this specimen could just be exceptionally large.

Specimen L4571, S15349.

Specimen S15349 was placed with *Lampsilis consueta* on the majority-rule consensus tree with 50% confidence. In this case, the tree did not seem to work well as *Plesielliptio stantoni* seems to be a better placement.

The shell is more similar to *Plesielliptio stantoni* with *Plesielliptio*-like sculpture, a broad umbonal region, and a pronounced posterior ridge. Including internal traits may have pushed specimen S15349 farther from *P. stantoni* than intended as the type does not have an internal view. It is worth knowing that type specimens of *Lampsilis consueta* do not preserve beaks and so whether the species has sculpture, a key trait in diagnostics, and so it is difficult to rule out *L. consueta* from the assignment.

Specimen L4626, S15355.

Specimen S15355 was placed near *Plesielliptio priscus* on the majority-rule consensus tree with 50% confidence. Similar traits are elongate shell shape, relatively straight ventral margin, broadly convex dorsal margin, the specimen preserves umbonal sculpture with limited disc sculpture, a broad umbo that is not raised, anteriorly but not terminally placed beak and stratified growth line patterns.

The specimen differs in size (94.57 mm in length, types ranging from 64.41 mm to 72.49 mm), which is much larger than types, but this specimen could just be exceptionally large, as it shares many traits with USNM 29739a and 29739b.

Specimen L4625, S15351.

Specimen S15351 was not placed with a specific taxon in the majority-rule consensus tree, though it is close to several. The species that most closely resembles specimen S15351 is *Rhabdotophorus senectus*. Similarities to types (USNM 2478a, b, and c) include an elongate shell shape, medium shell convexity, and an almost terminally placed umbo.

The shell differs in size (73.61 mm in length, the only type measured for length was 82.59 mm for an 80% complete shell, and having *Plesielliptio*-like sculpture preserved on beaks, a trait not known to the genus *Rhabdotophorus.* The shell also does not preserve *Rhabdotophorus*-like sculpture as well. This could indicate an assignment to *Plesielliptio.*

Specimen L4625, S15339.

Specimen S15339 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (15.98 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines stronger near margins.

Specimen L4625, S15340.

Specimen S15340 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (13.61 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines stronger near margins.

It's worth noting the posterior margin is not as elongate as in other *Corbula* subtrigonalis specimens. This almost resembles *Corbicula occidentalis* (USNM 2134), but is not quite that shortened. With all other traits matching *C. subtrigonalis*, it seems that is the best placement for specimen S15340.

Specimen L6924, S15415.

Specimen S15415 was placed with *Plesielliptio subspatulatus* in the majority-rule consensus tree with 100% confidence. Similar features include elongate shell, a relatively straight dorsal margin, a kink in the ventral margin, a nearly terminally place umbo, and lacking beak sculpture (though likely because of preservation).

The shell differs from *Plesielliptio subspatulatus* in size (55.99 mm in length, types of *P. subspatulatus* range from 61.9 mm to 84.5 mm), though it is not much smaller. It also has a more angular posterior margin than *P. subspatulatus*, a trait that is seen in similar shaped *Plesielliptio danae* (USNM 2163, 75.54 mm in length to 84.73 mm).

Specimen L6924, S15416.

Specimen S15416 was placed with *Rhabdotophorus senectus* in the majority-rule consensus tree with 50% confidence. After viewing the specimen, it looks as though it should be placed with nearby *Plesielliptio danae.* Similar features to *P. danae* include elongate shell, broadly convex dorsal margin, a kink in the ventral margin, lack of sculpture (though likely because of preservation), near terminally placed beaks, beaks low on the dorsum, and varied growth lines

The shell differs from *Plesielliptio danae* in size (59.24 mm in length, types of *P. danae* range from 75.54 mm to 84.73 mm). This could likely mean the shell is a sub-adult, but with other similar features *P.* danae seems like the right classification.

Specimen L6924, S15471.

Specimen S15471 was placed with *Plesielliptio danae* on the majority-rule consensus tree with 100% confidence. Similarities include elongate shell shape, convex dorsal margin, kink in the ventral margin, a marked curvature change on the posterior margin, lack of sculpture (though this could be because of preservation), a slight posterior ridge, near terminal beaks, size (81.1 mm in length, types range from 75.54 mm to 84.73 mm), and growth lines that vary in strength.

Specimen L6924, S15470.

Specimen S15470 was placed with *Plesielliptio danae* on the majority-rule consensus tree with 100% confidence. Similarities include elongate shape, broadly convex dorsal margin, kink in the ventral margin, lack of sculpture (though this could be due to preservation), slight posterior ridge, near terminal beak placement, and varied growth line thickness.

The shell is smaller than types of *Plesielliptio danae* (37.67 mm in length, types range from 75.54 mm to 84.73 mm). This could mean the shell is a sub-adult, as many above traits seem to indicate that *P. danae* is the correct placement for this specimen.

Specimen L4571, S15357.

Specimen S15357 was placed with *Plesielliptio deweyanus* in the majority-rule consensus tree with 75% confidence. Similar features include an elongate shell shape, broadly convex dorsal and ventral margins, *Plesielliptio*-like sculpture on the umbo and posterior ridge; posterior ridge is not very pronounced and stronger growth lines near the margins.

Scale is difficult to compare, as types of *Plesielliptio deweyanus* are incomplete. Specimen S15357 is 78.32 mm in length, while a 60% complete specimen of *P. deweyanus* is 55.59 mm.

Specimen L4571, S15383.

Specimen S15383 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (18.95 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines stronger near margins.

Specimen L4571, S15384.

Specimen S15384 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (18.58 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines stronger near margins.

Specimen L4620, S15353.

Specimen S15353 was not placed with any specific species on the majority-rule consensus tree, likely due to missing data. The nearest type specimen is *Plesielliptio deweyanus.* Similarities to *P. deweyanus* types (USNM 353897a, b, c, d, e, f) include an elongate shell shape, broadly convex ventral and dorsal margins, lack of sculpture (though could be because of preservation), near terminally placed beaks, and low placed beaks on the dorsum. Unfortunately, this specimen is obscured by matrix and is missing a lot of data, making species assignment difficult.

Specimen L7377, S15468.

Specimen S15468 was not placed with any specific species on the majority-rule consensus tree, likely due to missing data. The nearest type specimen is *Plesielliptio deweyanus* Similarities to *P. deweyanus* include an ovate shell shape, broadly convex dorsal and ventral margins, moderate shell convexity, lack of sculpture on umbo, anteriorly placed beaks. Unfortunately, this specimen is not very complete and is missing a lot of data, making species assignment difficult.

Specimen L4619, S15365.

Specimen S15365 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge and raised beaks placed anteriorly on the dorsum

The shell is 28.14 mm in length, types range from 10.4 mm to 24.47 mm. This difference does not seem large enough to suggest a separate species assignment.

Specimen L4619, S15336.

Specimen S15336 was placed with *Corbula subtrigonalis* on the majority-rule consensus tree with 56% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge, raised beaks placed anteriorly on the dorsum, size (25.74 mm in length, types range from 10.4 mm to 24.47 mm) and growth lines stronger near margins.

Specimen L4616, S15334.

Specimen S15334 was placed with *Corbula subtrigonalis* in the majority-rule consensus tree with 100% confidence. Similar features include triangular shell shape, a convex ventral margin, angular dorsal margin, a marked curvature change on the posterior margin, a convex anterior margin, lack of sculpture, pronounced posterior ridge and raised beaks placed anteriorly on the dorsum

The shell is 26.88 mm in length, types range from 10.4 mm to 24.47 mm. This does not seem large enough to suggest a separate species assignment, especially with similarities to *Corbula subtrigonalis.*

The following discussion diagnoses individual specimens from the Judith River Formation as part of an explanation of clustering association of species on the resulting consensus tree. Where possible, shell features are discussed in the following order: 1. Shell size, 2. Shell shape, 3. Number of whorls, 4. SWA measurements, 5. Spire elevation, 6. Whorl shape,

7. Suture indention, 8. Sculpture, 9. Aperture shape, and 10. Aperture lip description. Confidence of placement is based off the majority-rule consensus tree (Fig. 7), where percentage reported represents the percentage in which the number of created trees placed specimens as sister taxa.

Specimen L4617, S15393.

Specimen S15393 was placed near *Melanoides sublaevis* on the majority-rule consensus tree with 86% confidence. Similarities include size (27.19 mm in height, USNM 2145 is 23.01 mm in height), an elongate conic shell shape, Number of preserved whorls (6, USNM 2145 has 5.4), SWA measurements (29.9°, types range from 12.29° to 28.24°), very elevated spire, lightly convex whorls, lightly impressed sutures, and lack of sculpture

Specimen L4618, S15403.

Specimen S15403 was placed with *Campeloma vetulum pegmate* on the majority-rule consensus tree with 100% confidence. Similarities include a conic shell shape, SWA measurements (42.28°, USNM 75289 is 46.96°), elevated spire, convex whorls, impressed sutures, lack of sculpture, ovate aperture shape and strong and not reflexed basal and parietal lips.

Specimen S15403 differs in size (26.65 mm in height, USNM 75289 is 19.64 mm in height) though this is not a significant difference as S15403 has 6.24 whorls preserved while USNM 75289 has 3.96 and so that could make up the difference. Last whorl on specimen S15403 has maximum curvature on the basal section of the whorl, while USNM 75289 has a consistent curvature across the last whorl.

Specimen L4618, S15405.

Specimen S15405 was placed with *Campeloma vetulum* and *Campeloma vetulum pegmate* on the majority-rule consensus tree with 75% confidence. Similarities to *C. vetulum* include size (22.73 mm, types range from 23.33 mm to 24.25 mm in height), number of preserved whorls (4.54, types range from 5.04 to 5.86), elevated spire, convex whorl shape, indented sutures, lack of sculpture, an ovate aperture shape and pronounced (and not reflexed) basal and parietal lips.

Specimen S15405 differs from types of *Campeloma vetulum* in SWA measurement (45.27°, types range from 57.89° to 65.39°). A thinner shell does is a trait that separates *Campeloma vetulum pegmate* from *C. vetulum* and the type of *C. vetulum pegmate* has a SWA of 46.96°, which is similar to specimen S15405. Other traits (height, spire elevation, whorl shape, suture indention, aperture shape and lip description) are also shared with *C. vetulum pegmate.* Additionally, specimen S15405 was classified with a conic shell shape, which matches *C. vetulum pegmate* as *C. vetulum* was classified as ovately conic. Overall, *C. vetulum pegmate* seems to be the correct assignment, there is a small distinction between *C. vetulum* and this subspecies making distinguishing them on the basis of traits difficult.

Specimen L4619, S15409.

Specimen S15409 was placed with *Lioplacodes gracilenta* on the majority-rule consensus tree, though the specimen seems more like *Lioplacodes praecursa,* as it is not far removed (86% confidence). Similarities to *L. praecursa* include a conic shell shape, number of preserved whorls (5.23, type preserves 4.5), an elevated spire, convex whorl shape, indented suture, lack of sculpture, and a narrowly ovate aperture (though it is somewhat distorted)

Specimen S15409 differs in SWA measurement (36.15°, type is 25.55°) though this is not so far off, specimens of *Lioplacodes invenusta* (USNM 2144a-l) range from 20.1° to 38.11°, and so such a difference is not unheard of in the genus. Size is also different (28.07 mm in height, type is 20.25 mm in height), though again this is not significantly different. When considering how similar other traits are and how minimal the differences are *Lioplacodes praecursa* seems like the best fit.

Specimen L4619, S15411.

Specimen S15411 was placed with *Campeloma vetulum* and *Campeloma vetulum pegmate* on the majority-rule consensus tree with 75% confidence. *Campeloma vetulum pegmate* seems to be the correct species. Similarities include size (24.05 mm in height, type (USNM 75289) is 19.64 mm in height), a conic shell shape, SWA measurement (43.16°, type is 46.96°), an elevated spire, convex whorl shape, indented sutures, lack of sculpture, and a strong but not reflexed parietal whorl.

The shell differs in number of whorls (5.15, type preserves 3.96) though specimen S15411 has more height than USNM 75289, which could be because of added whorls. Aperture shape is also different as USNM 75289 had an ovate aperture, while specimen S15411 had a D-shaped aperture. This could be because of distortion on specimen S15411, though any distortion would be minimal. Lastly, specimen S15411 has a strong, reflexed basal lip while USNM 75289 does not have a reflexed lip. It is worth noting that the basal lip is barely preserved on USNM 75289, so this trait could be missing.

Specimen L4620, S15395.

Specimen S15395 was placed with *Campeloma vetulum* on the majority-rule consensus tree, though *Campeloma vetulum pegmate* seems like a better assignment (75% confidence). Similarities to *C. vetulum pegmate* include height (17.21 mm in height, types (USNM 75289) is 19.64 mm in height), a conic shell shape, number of whorls (5, type has 3.96), SWA measurement (42.3°, type is 46.96°), elevated spire, convex whorl shape, indented sutures, lack of sculpture, and an ovate aperture shape (though much is destroyed on specimen S15395)

Specimen L4620, S15396.

Specimen S15396 was placed with *Lioplacodes invenusta* on the majority-rule consensus tree with 100% confidence. Similarities include size (20.13 mm in height, types (USNM 2144a-l) range from 14.93 mm to 22.13 mm in height), a narrowly conic shell shape, number of whorls (5, types range from 4.28 to 5.62), SWA measurement (27.62°, types range from 20.10° to 38.11°), an elevated spire, relatively flat whorls, lightly indented sutures, and lack of sculpture.

Aperture on S15396 is distorted and so is difficult to use in identification. It does look somewhat narrowly ovate in shape, while USNM 2144, a, b look circular. USNM 2144c however has a narrowly ovate aperture, which is close to what is seen on S15396.

Specimen L4620, S15399.

Specimen S15399 was placed with *Physa subelongata* and *Physa canadensis tenuis* on the majority-rule consensus tree with 63% confidence. General shell shape however, looks more like *P. canadensis tenuis*. Similarities include shell shape (lynmaeaform), number of whorls (6, types preserve 5), SWA measurement (31.02°, types range from 27.93° to 42.66°), a somewhat elevated spire that is very thin, lightly indented sutures, lack of sculpture, a narrowly ovate aperture, and strong but not reflexed basal and parietal lips.

Specimen S15399 differs from *Physa canadensis tenuis* in that it coils dextrally, whereas *Physa* coils in a sinistral nature. Specimen S15399 is smaller (14.84 mm in height, figured specimen #24 preserves 36.29 mm in height). Specimen S15399 also shows a trait unique to this specimen and a few others of similar morphology, which is a double fold in the columella. Because of this trait and dextral coiling, this specimen and others like it were placed under "Species A" because they do not match anything else currently known and could be a new species.

Specimen L7300, S14264.

Specimen S15264 was placed with *Physa subelongata* and *Physa canadensis tenuis* on the majority-rule consensus tree with 93% confidence. General shell shape however, looks more like *P. canadensis tenuis*. Similarities include shell shape (lynmaeaform), number of whorls (5.08, types preserve 5), SWA measurement (41.74°, types range from 27.93° to 42.66°), a somewhat elevated spire that is very thin, lightly indented sutures, lack of sculpture, a narrowly ovate aperture, and strong but not reflexed basal and parietal lips.

Specimen S14264 differs in that it coils dextrally, whereas *Physa* coils in a sinistral nature. The specimen is smaller (21.63 mm in height, figured specimen #24 preserves 36.29 mm in height). Specimen S14264 also shows a trait unique to this specimen and a few others of similar morphology, which is a double fold in the columella. Because of this trait and dextral coiling, this specimen and others like it were placed under "Species A" because they do not match anything else currently known and could be a new species.

Specimen L7300, S14286.

Specimen S14286 was placed with *Viviparus nidaga* on the majority-rule consensus tree with 100% confidence. Similarities include a broadly conic shell shape, number of whorls (4.88, types range from 4 to 4.84), SWA measurement (69.27°, types range from 59° to 66.55°), a not very elevated spire, convex whorls, indented sutures, lack of sculpture, a circular aperture, and weak and not reflexed basal and parietal lips.

Specimen S14286 differs from *Viviparus nidaga* only slightly in size (23.53 mm in height, types range from 30.47 mm to 40.45 mm in height), though this is not a significant difference.

Specimen L7377, S15469.

Specimen S15469 was placed with *Campeloma vetulum pegmate* on the majority-rule consensus tree with 97% confidence. Similarities include size (20.85 mm in height, USNM 75289 is 19.43 mm in height), a conic shell shape, number of whorls (4.86, USNM 75289 has 3.96), SWA measurement (47.69°, USNM 75289 is 46.96°), an elevated spire, convex whorls, indented sutures, lack of sculpture, an ovate aperture (specimen S15469 is slightly distorted), and strong but not reflexed basal and parietal lips.

Specimen L7378, 15465.

Specimen S15465 was placed with *Campeloma vetulum pegmate* on the majority-rule consensus tree with 33% confidence. Similarities include size (22.93 mm in height, USNM 75289 is 19.64 mm in height), a conic shell shape, SWA measurement (42.47°, USNM 75289 is 46.96°), an elevated spire, convex whorls, indented sutures, lack of sculpture, and an ovate aperture.

Specimen S15465 differs from *Campeloma vetulum pegmate* in number of preserved whorls (5.62, USNM 75289 preserves 3.96), though this could be the reason it is taller as USNM 75289 is missing the upper apex. Apertural lips are not preserved on specimen S15465 and so cannot be used for diagnoses.

Specimen L7378, S15473.

Specimen S15473 was placed with *Lioplacodes invenusta* on the majority-rule consensus tree with 100% confidence. Similarities include size (24.3 mm in height, USNM 2144a-l range from 19.88 mm to 22.27 mm in height), elongate conic shell shape, number of preserved whorls (6, USNM 2144a-l range from 4.28 to 5.62), SWA measurement (27.25°, types range from 20.1° to 38.11°), an elevated spire, lightly convex whorls, slightly indented sutures, lack of sculpture, and a not reflexed parietal lip.

Specimen L7380, S15489.

Specimen S15489 was placed with *Campeloma vetulum* on the majority-rule consensus tree with 100% confidence. Similarities include size (22.05 mm in height, USNM 29556a-e range from 23.33 mm to 24.25 mm in height), conic shell shape, number of preserved whorls (5.79, USNM 29556a-e range from 5.04 to 5.86), and elevated spire, convex whorls, indented sutures, lack of sculpture, an ovate aperture shape (though specimen S15489 is obscured slightly by matrix), and strong not reflexed basal and parietal lips.

Specimen S15489 differs from *Campeloma vetulum* slightly in SWA measurement (50.9°, USNM 29556a-e range from 57.89° to 65.39°), though this is not much smaller. It is worth noting that it is close to *Campeloma vetulum pegmate* (46.96°), but other traits seem to match *Campeloma vetulum*.

Specimen L4578, S15400.

Specimen S15400 was placed with *Viviparus montanaensis* on the majority-rule consensus tree with 100% confidence. Similarities include size (4.35 mm in height, USNM 29667a, b range from 4.3 mm to 5.1 mm in height), a broadly conic shell shape, number of preserved whorls (4, types range from 2.96 to 3.17), SWA measurement (147.64°, types range from 125.05° to 135.24°), a depressed spire, rounded whorls, indented sutures, lack of sculpture, and a circular aperture shape.

Specimen L4563, S15401.

Specimen S15401 was placed with *Viviparus montanaensis* on the majority-rule consensus tree with 100% confidence. Similarities include size (4.81 mm in height, USNM 29667a, b range from 4.3 mm to 5.1 mm in height), a broadly conic shell shape, number of preserved whorls (4.38, types range from 2.96 to 3.17), SWA measurement (131.09°, types range from 125.05° to 135.24°), a depressed spire, rounded whorls, indented sutures, lack of sculpture, and a circular aperture shape.

Specimen L7194, S14233.

Specimen S14233 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 88% confidence. Similarities include height (5.11 mm in height, USNM 353606a is 6.18 mm in height), a conic shell shape, number of preserved whorls (4.76, holotype is 4.92), an elevated spire, lightly indented sutures, and lack of sculpture.

It differs in having more convex whorls than the holotype. Additionally, SWA measurement is higher for specimen S14233 (34.68°, holotype is 18.4°).

Specimen L7194, S14234.

Specimen S14234 was placed with "*Hydrobia" subconica* in the majority-rule consensus tree with 100% confidence. Similarities include size (2.54 mm in height, USNM 353606b is USNM 2184 is 6.68 mm in height), a conic shell shape, number of whorls (4.23, USNM 353606a, b range from 3.02 to 4.14), SWA measurement (65.61°, types range from 46.96° to 57.48°), an elevated spire, a lightly convex whorl shape, lightly indented sutures, lack of sculpture, and an ovate aperture.

Specimen L7194, S14235.

Specimen S14235 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 88% confidence. Similarities include size (6.64 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, number of preserved whorls (5.36, holotype is 4.92), a very elevated spire, lack of sculpture, and an ovate aperture.

Specimen S14235 differs from *Melanoides? omitta* in SWA measurement (32.55°, holotype is 18.4°) meaning it is wider in shape. Specimen S14235 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.*

Specimen L7194, S14236.

Specimen S14235 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 88% confidence. Similarities include size (4.54 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, number of preserved whorls (5.53, holotype is 4.92), a very elevated spire, and lack of sculpture

Specimen S142356 differs in SWA measurement (32.62°, holotype is 18.4°) meaning it is wider in shape. Specimen S14236 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.*

Specimen L7194, S14237.

Specimen S14237 was placed with "*Hydrobia" subconica* on the majority-rule consensus tree with 100% confidence. Similarities include size (4.75 mm in height, USNM 353606b is 6.23 mm in height), a conic shell shape, number of preserved whorls (3.96, types range from 3.02 to 4.14), an elevated spire, lightly indented sutures, and an ovate aperture shape.

Specimen S14237 differs from "*Hydrobia" subconica* in SWA measurement (68.6°, types range from 46.96° to 57.48°), wider than types. It also has slightly more convex whorls than types of "*Hydrobia" subconica*, with the last whorl almost rounded, while the last whorl in "*H." subconica* types is less convex.

Specimen L7194, S14238.

Specimen S14238 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 86% confidence. This does not seem like the right placement as "*Hydrobia" subconica* seems like the correct species. Similarities include size (4.64 mm in height, USNM 353606b is 6.18 mm in height), and conic shell shape, number of preserved whorls (3.94, types range from 3.02 to 4.14), an elevated spire, lack of sculpture, and an ovate aperture.

Specimen S14238 differs from *Melanoides? omitta* in that its whorls are more convex than USNM 353606b, and having more indented sutures. These traits are significant (as described later), though USNM 353606a has a whorl convexity and suture indention that is somewhat similar to specimen S14238.

Specimen L6927b, S14239.

Specimen S14239 was placed with "*Hydrobia" subconica* on the majority-rule consensus tree with 100% confidence. Similarities include size (3.54 mm in height, USNM 353606b is 6.23 mm in height), a conic shell shape, number of preserved whorls (3.46, types range from 3.02 to 4.14), an elevated spire, lightly indented sutures, and an ovate aperture shape.

Specimen S14239 differs in SWA measurement (71.5°, types range from 46.96° to 57.48°), wider than types. It also has slightly more convex whorls than types of "*Hydrobia" subconica*, with the last whorl almost rounded, while the last whorl in "*H." subconica* types is less convex.

Specimen L6927b, S14240.

Specimen S14235 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 86% confidence. Similarities include size (4.5 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, a very elevated spire, lack of sculpture, and an ovate aperture.

Specimen S14240 differs from *Melanoides? omitta* in SWA measurement (32.55°, holotype is 18.4°) meaning it is wider in shape. Specimen S14235 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.* Lastly, number of preserved whorls (3, holotype is 4.92) is less than the holotype of *M.? omitta*, a trait that in comparable to is somewhat smaller size.

Specimen L6926c, S14244.

Specimen S14244 was placed with “*Hydrobia” recta* on the majority-rule consensus tree with 68% confidence. Similarities include size (7.54 mm in height, USNM 29586a, b range from 4.96 mm to 7 mm in height), an elongate conic shape, number of preserved whorls (5.93, holotype is 6.24), a very elevated spire, lack of sculpture, and an ovate aperture.

Specimen S14244 differs from “*Hydrobia” subconica* in having slightly more convex whorls and more indented sutures. These traits are not much different from type specimens to cause a separate diagnosis. Unfortunately, because matrix obscures specimen S14244’s last suture, SWA could not be measured, which could aid in successfully placing the specimen.

Specimen L6926c, S14246.

Specimen S14246 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 86% confidence. Similarities include size (3.68 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, number of preserved whorls (4.23, holotype is 4.92), a very elevated spire, and a lack of sculpture.

Specimen S14246 differs from *Melanoides? omitta* in SWA measurement (44.61°, holotype is 18.4°) meaning it is wider in shape. Specimen S14246 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.* Aperture is broken on the specimen, which could aid in successfully diagnosing its species.

Specimen L6926c, S14247.

Specimen S14247 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 86% confidence. Similarities include size (9.88 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, number of preserved whorls (6, holotype is 4.92), a very elevated spire, and a lack of sculpture.

Specimen S14247 differs from *Melanoides? omitta* in SWA measurement (49.82°, holotype is 18.4°) meaning it is wider in shape. Specimen S14247 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.* Size of the specimen is somewhat larger than type, though it also preserves more whorls, which could cause the difference.

Specimen L6927a, S14255.

Specimen S14255 was placed with "*Hydrobia" subconica* on the majority-rule consensus tree with 100% confidence. Similarities include size (3.45 mm in height, USNM 353606b is 6.23 mm in height), a conic shell shape, number of preserved whorls (3.61, types range from 3.02 to 4.14), an elevated spire, lightly indented sutures, and an ovate aperture shape.

Specimen S14255 differs from "*Hydrobia" subconica* in SWA measurement (67.67°, types range from 46.96° to 57.48°), wider than types. It also has slightly more convex whorls than types of "*H." subconica*, with the last whorl almost rounded, while the last whorl in "*H." subconica* types is less convex.

Specimen L6927a, S14259.

Specimen S14259 was placed with *Melanoides? omitta* on the majority-rule consensus tree with 86% confidence. Similarities include size (5.88 mm in height, USNM 2184 is 6.68 mm in height), an elongate conic shape, number of preserved whorls (4.83, holotype is 4.92), a very elevated spire, lack of sculpture, and an ovate aperture.

Specimen S14259 differs from *Melanoides? omitta* in SWA measurement (33.99°, holotype is 18.4°) meaning it is wider in shape. Specimen S14259 has whorls that are convex in shape and sutures that are more indented than the holotype of *Melanoides? omitta.*

Specimen L6927a, S14260.

Specimen S14260 was placed with "*Hydrobia" subconica* on the majority-rule consensus tree with 100% confidence. Similarities include size (4.82 mm in height, USNM 353606b is 6.18 mm in height), a conic shell shape, number of whorls (4.43, types range from 3.02 to 4.14), an elevated spire, lightly convex whorls, lightly indented sutures, lack of sculpture, and an ovate aperture shape,

Specimen S14269 differs from "*Hydrobia" subconica* in SWA measurement (36.13°, types range from 46.96° to 57.48°), which is smaller, but other similarities deem this diagnosis as correct.

OVERVIEW OF TREES

Phylogenetic analysis presents a strong method for identifying molluscan species in the Judith River Formation. Types placed near each other, such as *Plesielliptio, Corbula,* and *Physa*, indicate situations where the approach succeeded in its goals of accurately identifying these specimens. With taxa such as "*Hydrobia"* and *Lampsilis,* types did not cluster together, signifying missing data, convergence or other problems with character definitions. In the case of "*Hydrobia"* taxa, size alone did not separate them from other genera, as this is a relatively noticeable difference. *Lampsilis*, did not separate from *Plesielliptio* because the amount of missing data.

The dataset showed a high number of constant and parsimony uninformative traits. In the case of snails, these traits centered on sculpture (where six traits have a CI (Consistency Index) and RI (Retention Index) are 1.00 where they were constant or 0.00 where they were representing a trait that is uninformative. This does not mean that these traits need to be removed from future analyses, as additional specimens could exhibit these traits. The Judith River Formation has a few species that exhibit sculpture (*Melanoides convexa, Melanoides convexa impressa, Lioplacodes judithensis*) and so these traits were useful for separating these genera from one another (*Melanoides* was clustered together likely on inclusion of axial sculpture). This sample simply did not include any specimens that exhibited sculpture, and so effectiveness of these traits remains ultimately untested.

Because many types do not preserve internal traits (e.g., *Plesielliptio stantoni, Plesielliptio priscus, Lampsilis consueta,* and *Anodonta propatoris)*, dentition and internal traits provided little information useful for species diagnosis. The opposite was true for many unknowns who do not preserve internal views, when their proposed types do. Internal traits were the most common source for missing data in large clams and so likely contributed to mismatched placements of both types and unknown specimens. *Lampsilis consueta* is a great example. Because of poor preservation of the types, and a shell shape similar to *Plesielliptio*, it was difficult to place any specimen definitively with this taxon. Thirty-four of clam internal traits exhibited a low RI or CI (meaning they were not parsimony informative), though likely this was because many specimens did not preserve internal traits, making it difficult to use them in the analysis as they caused specimens who might share a good portion of external traits to be separated when they differed in internal traits because one did not preserve internal views. This did not necessarily mean that internal traits should be removed from the study as internal traits can provide a strong basis for species diagnoses in the future, as better-preserved specimens are collected.

Specimens are rarely complete and so many specimens that were measured and analyzed were missing data due to preservation issues. The Judith River Formation has a variety of preservation states ranging from detailed, original shell material, to very poor where little to no shell material is preserved. Many of these issues surround the fact that much of the type material for Judith River Formation mollusks is incomplete or poorly preserved. Without solid preservation of type material, it was difficult to match specimens to the specific type. Good examples are *Anodonta sp.* and *Lampsilis consueta*. *Anodonta sp.* figured material consists of only an internal mold with no shell material preserved. Because of this, it was impossible to place the specimen within the genus *Anodonta* and it was subsequently removed from the study. *Lampsilis consueta* figured specimens exclusively preserve internal and external molds, with only one specimen (USNM 29699a) preserving any shell material and it was difficult to be confident in its placement. In a few cases, the tree did not place species with other species of their genus, these were examples of missing data (e.g., *Anodonta*) and additional collections can help solidify cataloged traits represented in the species.

These preservation issues were most noticeable in large unionid clams. These specimens were generally poorly preserved, and highly exfoliated in the Lower Judith River Formation of Kennedy Coulee (L7224, L7300). Commonly, the umbonal region of shells did not preserve, which can be important to identifying a specimen, as much of unionid sculpture is found on the beaks and umbo. In the Upper Judith River Formation (L6927a-c; L6926c), preservation was better and many of these specimens were confidently placed with a species. Smaller clams, such as *Corbula subtrigonalis, Corbula undifera, and Sphaerium* taxa tended to have excellent preservation, in many cases complete shells with clean internal views (specimens S15334, S15336, S15390, and S15329). This lead to an overall higher confidence in specimens placed with these taxa.

Overall, the approach used is effective for continuing to diagnose species in the Judith River Formation. Transparency and repeatability add strength to this study. In the past, Meek and Hayden (1854, 1856, 1857) placed specimens within a taxon based on simple descriptions. This is difficult to reproduce, especially since diagrams of measurements taken are not usually available. This means there is difficulty telling what the measurements provided mean. Additionally, these descriptions rarely refer to a specific specimen for traits that do not require measurements. This study used a reference specimen to help identify traits that were not measured. This still allows a certain amount of repeatability as photos of reference specimens are available and so future work can still refer to them and develop a measurement range if needed. Another strength of this methodology is added robustness provided by combining the result of over 90,000 created trees to ensure that associations made are based off consistent results.

EVALUATION OF IDENTIFICATION TECHNIQUE

Certain Identifications

Examples of specimens that were confidently diagnosed a species include specimens S15396, S14286, S15470 and S15486. Specimen S15396 was placed with *Lioplacodes invenusta* with 100% confidence. The specimen shares 30 out of 34 traits with types of *L. invenusta.* All but one of these shared traits are considered informative (having an RI greater than 0.5). Some diagnostic traits that separated specimen S15396 from nearby species were suture indention (CI of 0.27, RI of 0.7), MSA (CI of 0.5, RI of 0.71) and SWA (CI of 0.25, RI of 0.74). These traits all proved important in that they have a low number of steps compared to possible character states meaning that they are synapomorphies with little evidence of convergence. This makes them traits important for identification as they can be narrowed down to specific group of sister taxa. Specifically, MSA had three possible character states and four steps, meaning that it was very informative by grouping every specimen with each character state together, with one example of convergence, a specimen separated from specimen S15396 by size (CI of 0.25, RI of 0.74). Within the larger ingroup, having shallow sutures only appeared once and placed the specimen with both *L. invenusta* and the genus *Melanoides.* What separated specimen S15396 from *Melanoides* is the fact that it lacks sculpture, a trait both *Melanoides convexa* and *Melanoides convexa impressa* exhibit. These separations indicate that *L. invenusta* is the only plausible placement for specimen S15396.

Specimen S14286 was placed with *Viviparus nidaga* on the majority-rule consensus tree with 100% confidence, placing its own ingroup. Important traits include MSA (CI of 0.5, RI of 0.71), aperture shape (CI of 0.5, RI of 0.71) and SWA (CI of 0.25, RI of 0.74). Specimens of *Viviparus nidaga* have a very distinct SWA of ~65° and MSA of ~60°. Both of these traits were informative, though MSA had significantly lower steps per character state, four steps for three possible states. The large MSA measurement on *V. nidaga* and specimen S14286 was only otherwise represented in "*Hydrobia" subconica* (56°), *Campeloma vetulum* (53° to 61°) and *Campeloma vetulum pegmate* (56°). Specimen S14286 differed from "*H." subconica* in size (30 mm to 40 mm in height, compared to 6 mm), making that assignment unlikely. *Campeloma* *vetulum* and *C. vetulum pegmate* are similar in size, but differed significantly in aperture shape (*C. vetulum and C. vetulum pegmate* have an ovate aperture, while *V. nidaga* and specimen S14286 have circular apertures). This aperture shape was only represented by *V. nidaga* and specimen S14286.

Specimen S15470 was placed with *Plesielliptio danae* on the majority-rule consensus tree with 100% confidence. Three traits were prominent in this diagnosis; shell shape (CI of 0.62, RI of 0.88), ventral valve margin shape (CI of 0.67, RI of 0.75) and sculpture type (CI of 0.8, RI of 0.89). Shell shape as a trait had nine possible character states and represented 13 steps on the majority-rule consensus tree. The elongate shape of specimen S15470 is generally represented in the unionid mussels and larger shells, with some of these larger clams exhibiting a more ovate or even rounded shape (the four examples of convergence). Sculpture type separated it from other large unionids as the types lacked *Plesielliptio*-like sculpture. This separated it from other species that exhibit sculpture such as other typical specimens of *Plesielliptio* and *Rhabdotophorus. Plesielliptio danae*, *Plesielliptio subspatulatus* and *Plesielliptio deweyanus* exhibit a "kink" in the ventral margin, which specimen S15470 shares. *Plesielliptio subspatulatus* and *P. deweyanus* tend to have more elongate shells, while *P. danae* and specimen S15470 are more lanceolate in shape, a key synapomorphy that separates specimen S15470 and *P. danae* from other *Plesielliptio* species. Additionally, posterior margin shape (CI of 0.5, RI of 0.93) angularity is another synapomorphy that *P. danae* and specimen S15470 share that separated them from other specimens of *Plesielliptio.*

Specimen S15486 was placed with *Sphaerium recticardinale* with 100% confidence. The two specimens shared all 34 traits examined. One of the first traits that were defining in this diagnosis was the plesiomorphic state of having a small shell (<15 mm in length, CI of 0.33, RI of 0.91). Size helped to separate the specimen from larger clams and mussels and placed specimen S15486 with *Sphaerium* and *Corbula.* Shell shape (CI of 0.62, RI of 0.88) was important as *Sphaerium recticardinale* was the only species with a rectangular shell form, so this synapomorphy separated this specimen from other small clams. Lastly, a trait that was important to separating specimen S15486 from other specimens of *Sphaerium* was beak height (CI of 0.57, RI of 0.92), where specimen S15486 has a more pronounced umbo compared to other species of *Sphaerium*, much like types of *Sphaerium recticardinale.*

Relatively Strong Identifications

Examples of specimens that were identified, but with a lower confidence include specimens S15336 and S15440. Specimen S15336 was placed with *Corbula subtrigonalis* with 56% confidence. The only external difference between specimen S15336 and the type of *C. subtrigonalis* is H/L ratio (CI of 0.22, RI of 0.83), this trait grouped it with another six taxa that shared that character state, resulting in an outgroup from the grouping that includes the types of *C. subtrigonalis*. The system removed these specimens from the polytomy that includes *C. subtrigonalis* because they included internal traits, which types of *C. subtrigonalis* lacked. These internal traits, represented by "?" on the type specimen trait, resulted in a large number of traits that differed from the types. Likely, the system considered this difference a synapomorphy, resulting in the group excluding the *C. subtrigonalis* polytomy. These specimens were still placed in an ingroup with the *C. subtrigonalis* type, making this diagnosis relatively strong.

Specimen S15440 was placed with *Sphaerium planum* with 93% confidence. This specimen was close to 100% but was slightly separated by two external traits. These two traits were umbo genus sculpture (CI of 1, RI of 0) and escutcheon length (CI of 0, RI of 0) which would have likely made the specimen 100% confidently placed with *Sphaerium planum.* One reason this was still considered a good identification is that both of these traits were not very indicative of tree topology (having low RI values). Another reason is that types for *S. planum* are missing shell material on the umbo making sculpture unavailable to examine. Considering the two missing traits, *S. planum* is still very likely the correct species for specimen S15440.

Weak Identifications

Some specimens were not placed with a species that matched their traits. In this case, the approach of the study failed in its goals. A number of issues will be explained below, as they are essential to understanding how the analysis works and how future work can possibly rectify these shortcomings. These issues include binning errors and preservation errors/missing data.

Examples of specimens not placed confidently with a species include S14280 and S15354. Specimen S14280 was not placed near any species on the tree. Specimen S14280 shares significantly less traits with nearby *Plesielliptio stantoni* as more confident placements, which likely lead its lack of confident placement. This difference includes ten traits that are strongly consistent with the tree topology (CI and RI greater than 0.5). Some important traits include: umbo sculpture type (CI of 0.80, RI of 0.89), which is generally missing from type specimens because of preservation, growth line pattern (CI of 0.5, RI of 0.89) because they were not preserved, and extent of sculpture on the disc (CI of 0.67, RI of 0.92) was not preserved on the specimen. Extent of sculpture on the disc had three possible states and three steps making it useful for diagnosing species. In this case, missing data, and exfoliation make this specimen difficult to assign to a species. *Plesielliptio*-like sculpture does seem to suggest a *Plesielliptio* genus assignment, which still makes it useful for ecological analysis.

Specimen S15354 was not placed near any species on the majority-rule consensus tree. The nearest type specimen is *Plesielliptio stantoni*. Shell shape was similar (CI of 0.33, RI of 0.91), and broad umbo shape (CI of 0.33, RI of 0.93). Issues are related to specifics about the umbo, as it has been reconstructed on the type and so missing a lot of important data. Some missing traits were sculpture type (CI of 0.8, RI of 0.89), beak placement (CI of 0.5, RI of 0.79) and sculpture on the umbo (CI of 0.67, RI of 0.91). This missing data resulted in the specimen very like *P. stantoni* in many cases, but differing enough in the missing data to not place specimen S15354 definitively with the type. Many of these traits that center on the umbo have high CI and RI numbers, meaning they fit the trees topology well, and if these traits are missing it is much more difficult to place the specimen.

Highly Ambiguous Specimens

Specimen "A" (S15399, S14264), which was placed with *Physa subelongata, Physa canadensis tenuis* and *Physa copei*, is thought to be an unknown species. The shell is similar in morphology to *Physa canadensis tenuis* in that it has a very narrow spire that is extremely fragile and difficult to have preserved. Body whorl is similar in shape to *P. canadensis tenuis* and is elongate and tall, comprising most the shells height. Both shells have a convex last whorl with flattened spire whorls, leading to less indented sutures. Specimens of Species "A" are smaller than figured specimens of *P. canadensis tenuis* (14.83 mm to 21.63 mm in height, compared to 30.37 mm to 43.06 mm in height). Shells of the genus *Physa* have a sinistral coiling and are not known to be variable in this trait (Wandelt and Nagy, 2004) meaning the shell cannot belong to *Physa canadensis tenuis* despite a multitude of similar traits. Another trait that separated Species "A" from *P. canadensis tenuis* is a double fold feature on the columella inside the aperture. This trait is seen in the genus *Lymnaea* (Paraense, 1982), which many above traits matched as well, including the dextral coiling, and so *Lymnaea* is a likely placement for this specimen. Weighting of the coiling trait could prove useful for better separating these specimens out. This would be problematic in that it would reduce the assumption of each trait having the same weight.

Specimen S15492 was difficult to place on the majority-rule consensus tree, as the current study did not include marine species to which specimen S15492 seems to belong. A likely placement is the genus *Ostrea* to which brackish and marine specimens from the Judith River Formation and surrounding marine strata. Similarities to *Ostrea* included an elongate shell shape along the posterior and anterior margins. Posterior margin is broadly convex in shape, while the anterior edge is concave in shape. Ventral margin is convex, while the dorsal margin is distinctly angular. The shell is not very convex, with convexity of the shell consistent across the disc. The shell shows no sculpture. By branching this, studies focus out into brackish to marine faunas; accurate placement of this specimen could be accomplished using the same approach.

Specimens S14233, S14235, S14236, S14240, S14246, S14247 and S14259 were all placed with *Melanoides? omitta* in the majority-rule consensus tree, though they differed in some important traits. These specimens have whorls that are more convex than the type of *Melanoides? omitta*, and having less indented sutures. Additionally, SWA measurements of these specimens range from (32.55° to 49.82°) which is separate from other small species analyzed (*M.? omitta* 18.4°; "*Hydrobia" recta* 17.8° to 23.7°; "*Hydrobia" subconica* 46.96° to 57.48°). The most similar would be "*H." subconica* but, similarly to *M.? omitta*, these specimens have whorls that are more convex and less indented sutures. Apertures are similar to "*Hydrobia"*, and are ovate in shape, and height of the shells (all less than 10 mm in height). The specimens lack of sculpture (*Melanoides* is known to preserve axial sculpture). Because of these separate traits these specimens are better referred to as "*Hydrobia" sp. a* than any of the measured types. This genus assignment was inherited from many shared traits with "*Hydrobia"*. Small shells preserved in the Judith River Formation and contemporaneous formations are understudied, but at this time, it seems these specimens belong to a species of their own, possibly *Micropyrgus higdoni*, a small snail of the family Hydrobiidae, as they share a general shell shape.

Specimens S14237 and S14239 were placed with "*Hydrobia" subconica* on the majority-rule consensus tree but showed some significant differences. They are both smaller than "*H." subconica* types (3.54 mm to 4.75 mm in height, USNM 353606b is 6.23 mm in height). These specimens also differed from "*H." subconica* by having whorls that are more convex and more indented sutures. The last whorl is especially convex, almost rounded in shape, while the last whorl in "*H." subconica* tends to be more angular. Aperture shape in these two specimens is similar to "*Hydrobia"*, but S14237 shows a distinctly strong and angular basal lip, which in not seen in any of "*Hydrobia"* specimens. Specimen S14239 did not preserve the basal lip, though aperture shape is distinctly similar to specimen S14237 and so it likely preserves the same lip. For the purpose of this study, these two specimens will be placed into "*Hydrobia" sp. b* as they have many traits seen in "*Hydrobia"*, but were not similar enough to any type species in the analysis.

ECOLOGY AND DEPOSITIONAL ENVIRONMENT

Locality L7224 had nine specimens successfully identified by the majority-rule consensus tree. Of these specimens, the species *Sphaerium planum, Sphaerium recticardinale, Sphaerium subellipticum, Lampsilis consueta, Corbula subtrigonalis,* and *Corbula undifera* were identified. *Corbula* is primarily thought of as a brackish water clam, but Anderson et al. (2010) suggests that fossil specimens of the genus *Corbula* from the Miocene were actually members of the genus *Pachydon,* which is known from freshwater. Including the mussel *Lampsilis* and the fingernail clam *Sphaerium* suggests water with low salinity levels as they are both only found in freshwater today (Haag, 2012). This suggests that similarly, species of *Corbula* found at this locality and others throughout the Lower Judith River Formation were at least tolerant of fresh water, if not preferential to it. Additional work might look into evaluating placement of these species (and *Corbula subtrigonalis)* within *Corbula*, based upon these findings, by assessing morphological traits these species share with the genus *Pachydon*. Rogers et al. (2016) suggest that the lower sections of the Judith River Formation (McClelland Ferry Member) preserve fluvial floodplain and coastal mire facies that accumulate landward of the faster water Parkman Sandstone Member. This would suggest a number of environmental factors that presented genera agree with. First, L7224 consists of a grey, mudstone matrix that is indicative of slow moving waters typical of floodplains and lacustrine environments. Large clams litter the site. This is generally indicative of moving water, and the high abundance shows that the environment was ideal for these clams. The fingernail clam *Sphaerium* is known from slow moving, typically shallow water environments almost exclusively (Baker, 1921). This typically includes shallow pools, as part of a small woodland stream, or separated from moving water. *Lampsilis* and other mussels are typically known from riverine environments, though *Lampsilis* is found in slower sections of these rivers on muddy bottoms (Haag, 2012). As preferred environment for the Cretaceous fossil specimens of *Corbula* are debatable, we must rely on these other genera and local stratigraphy to make interpretations. It is interesting to note the lack of aquatic pulmonates such as *Physa* at this locality as (Gangopadhyay et al., 2012) suggests that they prefer slow, shallow waters. This could be an indication that the water was moving, such as a stream located in a floodplain. When considering the genera *Lampsilis* and *Sphaerium*, along with a mudstone lithology, it is likely that L7224 represents a slow-moving stream, where *Sphaerium* would rest in the small pools where the water was slow, while *Lampsilis* would prefer living deeper in the channel resting in mud where the water is slightly faster. This suggested environment is consistent with what is proposed Rogers et al. (2016) as the McClelland Ferry Member of the Lower Judith River Formation, and the lower unit of the Oldman Formation, representing isolated slow moving paleo-channels, with floodplains and pools.

Locality L4618 had five specimens confidently identified by a majority-rule consensus tree. Of these specimens, *Corbula undifera, Corbula subtrigonalis,* and *Campeloma vetulum pegmate* were identified. *Campeloma* is a pulmonate snail known from slow, shallow waters of streams and lakes, preferring to burrow in muddy substrates. *Corbula* is explained above as occurring with *Sphaerium* and *Lampsilis* in what is proposed as a locality deposited in slow moving, muddy waters. Lithology of the locality consists of dark brown sandstone and mudstone, which is consistent with ecology presented for identified genera preserved there. This locality is located near the base of Kennedy Coulee section, meaning it correlates with the top of the Foremost Formation or base of the Oldman Formation. The combination of taxa preserved and the mud and sand lithology suggest a slow stream or pool environment, which is consistent with proposed environments in the Lower Oldman Formation. Inclusion of *Campeloma* also suggests the substrate is muddy, where snails can burrow. The genus *Corbula* was again associated with taxa known from slow moving waters seems to suggest a preference to slow, fresh water, or a taxonomic reassignment for the taxa.

FUTURE WORK

This study sets up framework for accurate molluscan species diagnoses in the Judith River Formation. In using a robust, repeatable methodology, this study allows future work to accurately assign species diagnoses to molluscan specimens. This is useful in that mollusks can help identify depositional environments, including water depth, water speed and salinity, all of which can be useful in stratigraphic and paleontological studies. With the amount of vertebrate paleontological studies in the Judith River Formation of Kennedy Coulee, researchers can use the abundant molluscan specimens to establish environments these vertebrates inhabited. This study can also be expanded to other contemporaneous formations such as the Canadian Belly River Group and the Two Medicine Formation that outcrops in west-central Montana. Additionally, work can be done to enhance the methodology used as specimens that are more complete are discovered and described. With more complete specimens added to the database of assigned species, diagnoses that are more accurate become possible.

CONCLUSION

This study aimed to use phylogenetic analysis to diagnose species of freshwater mollusks of the Judith River Formation of north central and central Montana, with intent on using these diagnoses to more accurately assess depositional environment and ecology of localities studied. Two majority-rule consensus trees were constructed (one for gastropods and one for clams) by a heuristic search for parsimony. This analysis was based on morphological traits observed on both type and unknown specimens. In accomplishing this goal, and successfully identifying unknown specimens, interpretation on narrow-scale depositional environment was made possible. Localities for the Judith River Formation both near Rudyard and at the type area preserve a variety of fresh water habitats from slow moving pools and streams, to rivers with considerable water velocity. Additionally, overall preservation quality of the Judith River Formation was assessed in both type specimens and unknown specimens to better perfect future endeavors using this methodology. Lastly, the methodology used in this study set up a framework for true phylogenetic analyses to be performed on taxa of the Judith River Formation to better place them chronostratigraphically within the Upper Cretaceous fauna.

PLATES

Plate I.

1. ***Plesielliptio abbreviatus*** **(**Stanton, 1904: 108)

2*.* ***Pleurobema cryptorhynchus*** **(**White, 1877: 372)

3. ***Quadrula primaevus*** **(**White, 1877: 599)

4*.* ***Lampsilis consueta*** **(**Whiteaves, 1885: 59)

Plate I.

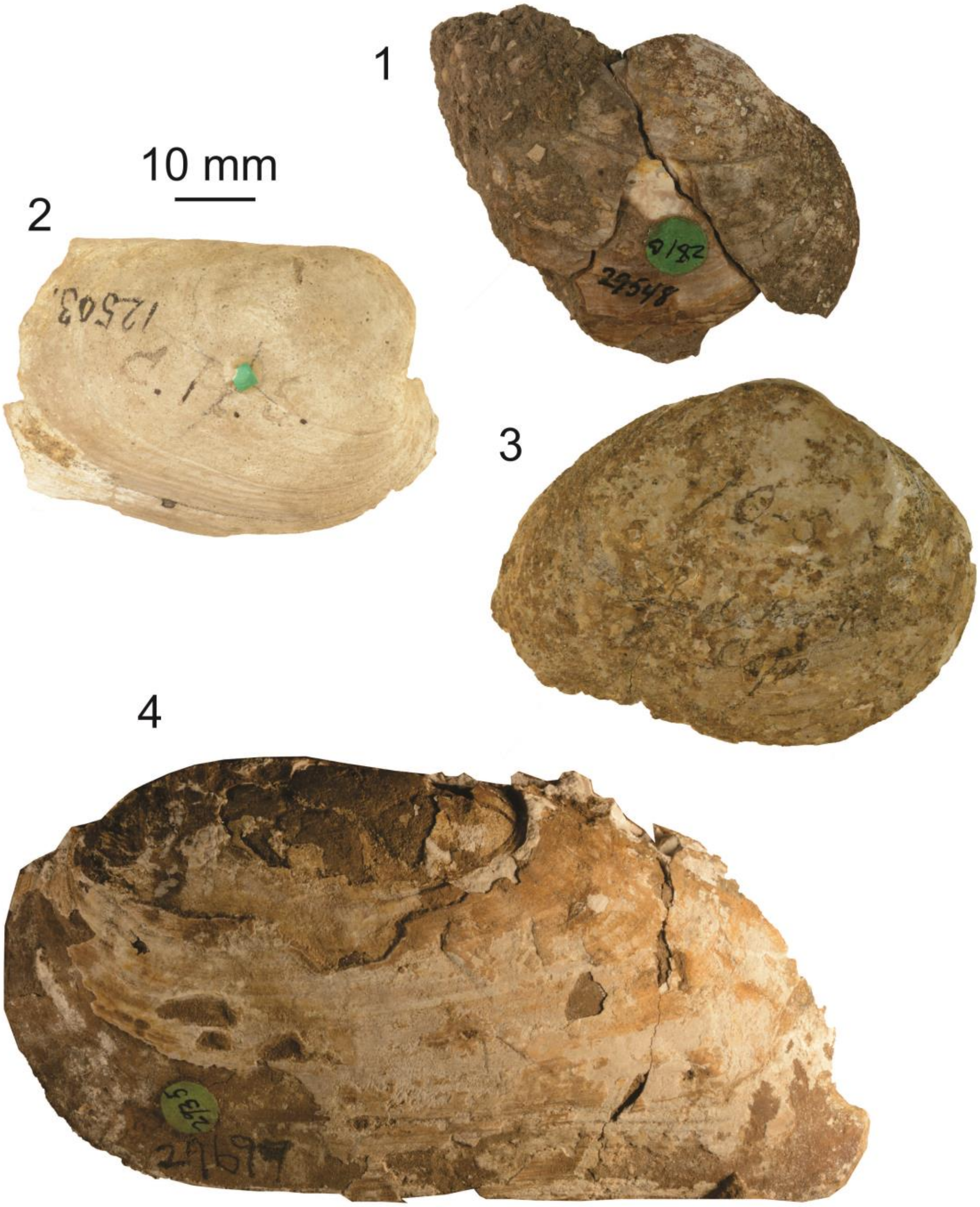


Plate II.

5. ***Anodonta propatoris*** White, 1877: 607

6. ***Plesielliptio danae*** **(**Meek and Hayden, 1857: 432)

7. ***Plesielliptio deweyanus*** **(**Meek and Hayden. 1857: 145)

8. ***Plesielliptio priscus*** **(**Meek and Hayden, 1856: 117)

Plate II.

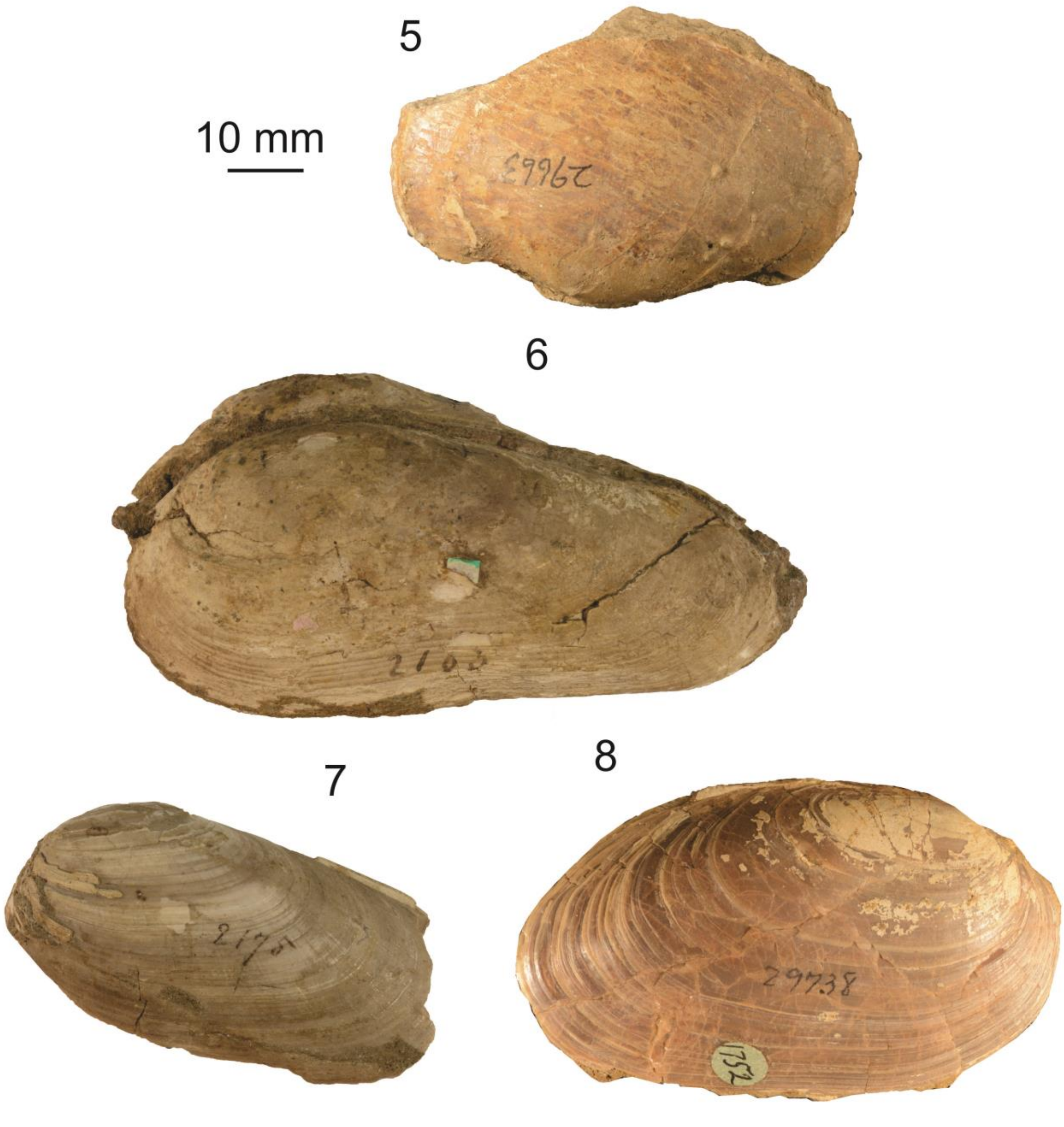


Plate III.

9. ***Rhabdotophorus senectus*** **(**White, 1877: 195)

10. ***Plesielliptio stantoni*** **(**White, 1905: 99)

11. ***Ptychobranchus subspatulatus*** (Meek and Hayden, 1857: 146)

12. ***Quadrula supenawensis*** **(**Stanton, 1904: 46)

Plate III.

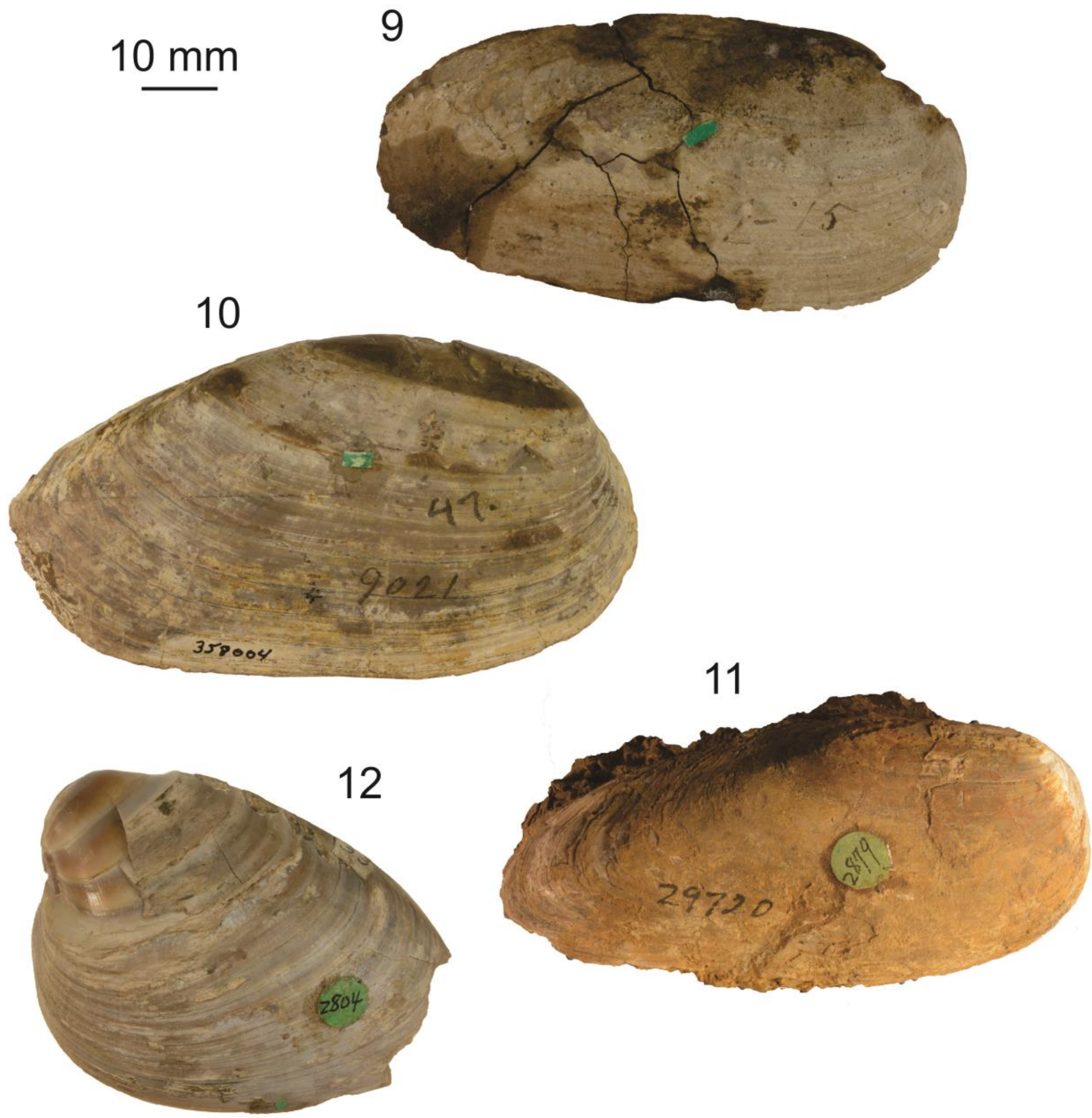


Plate IV.

13. ***Corbicula cytheriformis*** **(**Meek and Hayden, 1856: 116)

14. ***Corbicula occidentalis*** **(**Meek and Hayden, 1856: 116)

15. ***Corbula undifera*** Meek, 1873: 513

16. ***Corbula subtrigonalis*** Meek and Hayden, 1856: 116

17. ***Sphaerium planum*** Meek and Hayden, 1860: 175

18. ***Sphaerium recticardinale*** Meek and Hayden, 1860: 176

19. ***Sphaerium subellipticum*** Meek and Hayden, 1856: 115

Plate IV.

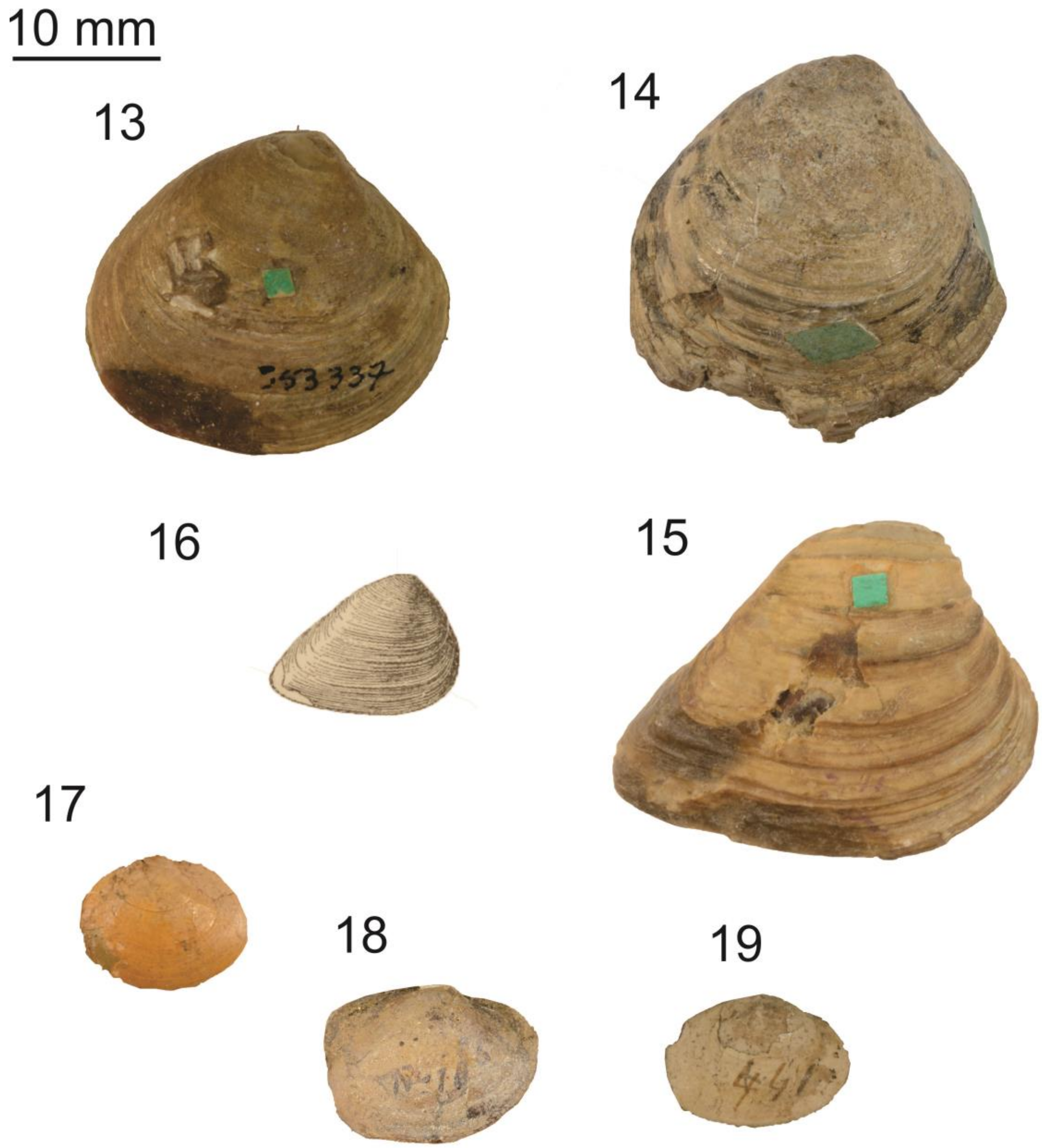


Plate V.

20. ***Aplexa atavus*** **(**White, 1877: 86)

21. ***Physa canadensis tenuis*** Russell, 1926: 216

22. ***Physa copei*** White, 1877: 602

23. ***Physa subelongata*** **(**Meek and Hayden, 1856: 120)

24. ***Melanoides convexa*** **(**Meek and Hayden, 1856: 125)

25. ***Melanoides convexa impressa*** **(**Meek and Hayden, 1857: 463)

26. ***Melanoides? omitta*** **(**Meek and Hayden, 1857: 220)

27. ***Melanoides sublaevis*** **(**Meek and Hayden, 1857: 136)

28a, b. ***Vitrina obliqua*** Meek and Hayden, 1857: 134

29. ***"Hydrobia" subconica*** **(**Meek 1876: 573)

30. ***"Hydrobia" recta USNM "Hydrobia" subcylindrica*** **(**White, 1876: 132)

Plate V.

Plate VI.

31. ***Viviparus conradi*** **(**Meek and Hayden, 1857: 579)

32a, b. ***Viviparus montanaensis*** **(**Meek, 1876: 591)

33. ***Viviparus nidaga*** Dyer, 1930: 9

34. ***Campeloma vetulum*** **(**Meek and Hayden, 1856: 121)

35. ***Campeloma vetulum pegmate*** Russell, 1934: 131

36a, b. ***Lioplacodes gracilenta*** **(**Meek, 1876: 633)

37. ***Lioplacodes invenusta*** **(**Meek and Hayden, 1857: 137)

38. ***Lioplacodes subtortuosa*** **(**Meek and Hayden, 1857: 319)

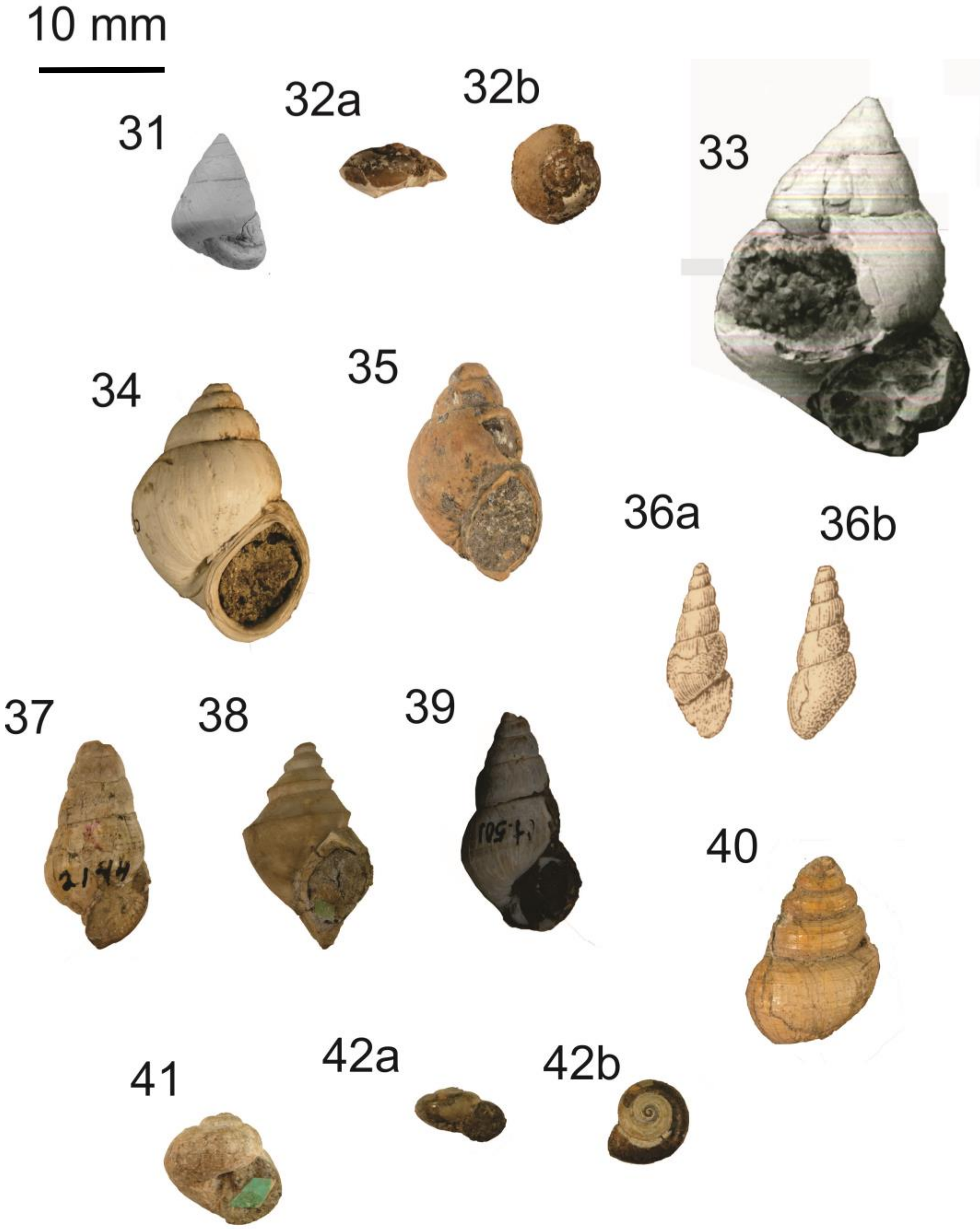
39. ***Lioplacodes praecursa*** Dyer, 1930: 11

40. ***Lioplacodes judithensis*** **(**Stanton and Hatcher, 1905: 117)

41. ***"Helix" vitrinoides*** Meek and Hayden, 1857: 309

42a, b. "***Helix" occidentalis*** Meek and Hayden, 1857: 137

Plate VI.



Locality Registry

Table 8. Locality registry. Data for localities sampled. Species identified at each locality is reported. * denote a questionable identification.

L Number	County	State	Section, T., R.	Formation
L4562	Hill	MT	19, 37 N, 9 E	JR
	Species:	*Corbula*	*undifera*	
L4563	Hill	MT	24, 37 N, 9 E	JR
	Species:	*Viviparus*	*montanaensis*	
L4571	Hill	MT	17, 37 N, 9 E	JR
	Species:	*Lampsilis*	*consueta*	
		Plesielliptio	*deweyanus*	
		Corbula	*subtrigonalis*	
L4578	Hill	MT	29, 37 N, 9 E	JR
	Species:	*Viviparus*	*montanaensis*	
L4617	Hill	MT	21, 37 N, 9 E	JR
	Species:	*Plesielliptio*	*stantoni*	
		Corbula	*subtrigonalis*	
		Melanoides	*sublaevis*	
L4618	Hill	MT	3, 37 N, 9 E	JR
	Species:	*Corbula*	*undifera*	
		Corbula	*subtrigonalis*	
		Campeloma	*vetulum pegmate*	
L4619	Hill	MT	3, 37 N, 9 E	JR
	Species:	*Corbula*	*subtrigonalis*	
		Lioplacodes	*gracilenta*	
		Campeloma	*vetulum pegmate*	
L4620	Hill	MT	6, 37 N, 9 E	JR
	Species:	*Corbula*	*undifera*	
		Plesielliptio	*deweyanus**	
		Campeloma	*vetulum*	
		Lioplacodes	*invenusta*	
		Species "A"		
L4625	Hill	MT	16, 37 N, 9 E	JR
	Species:	*Rhabdotophorus*	*senectus**	
		Corbula	*subtrigonalis*	
L4626	Hill	MT	31, 37 N, 9 E	JR
	Species:	*Plesielliptio*	*priscus*	
L6926c	Fergus	MT	29, 23 N, 22 E	JR
	Species:	*"Hydrobia"*	*recta*	
		"Hydrobia"	*sp. a*	

Table 8. cont.

L Number	County	State	Section, T., R.	Formation
L6927a	Fergus	MT	29, 23 N, 22 E	JR
	Species:	*Sphaerium*	*recticardinale*	
		Sphaerium	*subellipticum*	
		"Hydrobia"	*subconica*	
		"Hydrobia"	*sp. a*	
L6927b	Fergus	MT	29, 23 N, 22 E	JR
	Species:	*"Hydrobia"*	*sp. b*	
		"Hydrobia"	*sp. a*	
L6927c	Fergus	MT	29, 23 N, 22 E	JR
	Species:	*Sphaerium*	*recticardinale*	
L7194	Hill	MT	29, 37 N, 9 E	JR
	Species:	*"Hydrobia"*	*sp. a*	
		"Hydrobia"	*sp. b*	
L7224	Hill	MT	21, 37 N, 9 E	JR
	Species:	*Sphaerium*	*planum*	
		Sphaerium	*recticardinale*	
		Sphaerium	*subellipticum*	
		Lampsilis	*consueta*	
		Corbula	*subtrigonalis*	
		Corbula	*undifera*	
L7225	Hill	MT	29, 37 N, 9 E	JR
	Species:	*Corbula*	*undifera*	
		Corbula	*subtrigonalis*	
L7377	Hill	MT	29, 37 N, 9 E	JR
	Species:	*Plesielliptio*	*deweyanus**	
		Campeloma	*vetulum pegmate*	
L7378	Hill	MT	28, 37 N, 9 E	JR
	Species:	*Sphaerium*	*recticardinale*	
		Corbula	*subtrigonalis*	
		Lampsilis	*consueta**	
		Campeloma	*vetulum pegmate*	
		Lioplacodes	*invenusta*	
L7379	Hill	MT	28, 37 N, 9 E	JR
	Species:	*Sphaerium*	*recticardinale*	
L7380	Hill	MT	21, 37 N, 9 E	JR
	Species:	*Ostrea**		
		Sphaerium	*planum*	
		Campeloma	*vetulum*	

Table 8. cont.

L Number	County	State	Section, T., R.	Formation
L7300	Hill	MT	21, 37 N, 9 E	JR
	Species:	*Plesielliptio*	*stantoni**	
		Corbula	*subtrigonalis*	
		Species "A"		
		Viviparus	*nidaga*	

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APPENDICIES A. Measurements

Table 9. Measurements for unknown clams. Xs represent no measurement available. Measurements described in text. Measurements are in millimeters (mm).

Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
S11702	9.43	6.96	1.16	4.09	0.74	0.43	0.12	X	X	X	X	X	X	X
S11705	10.86	8.15	1.77	4.77	0.75	0.44	0.16	X	X	X	X	X	X	X
S11772	21.08	14.38	4.11	8.91	0.68	0.42	0.19	X	X	X	X	X	X	X
S14280	X	X	14.29	X	X	X	X	67.19	38.35	12.37	12.59	0.57	0.19	0.18
S14291	32.41	22.77	6.93	12.11	0.70	0.37	0.21	31.78	21.21	7.53	11.20	0.67	0.35	0.24
S14294	X	X	X	X	X	X	X	32.66	19.79	X	11.73	0.61	0.36	X
S15329	27.45	20.50	9.37	11.49	0.75	0.42	0.34	X	X	X	X	X	X	X
S15330	X	X	X	X	X	X	X	23.64	17.05	6.67	8.56	0.72	0.36	0.28
S15332	18.69	12.47	4.00	6.74	0.67	0.36	0.21	X	X	X	X	X	X	X
S15333	31.27	26.15	10.45	13.54	0.84	0.43	0.33	X	X	X	X	X	X	X
S15334	26.88	21.96	10.10	11.48	0.82	0.43	0.38	X	X	X	X	X	X	X
S15336	X	X	X	X	X	X	X	25.74	19.31	7.48	6.67	0.75	0.26	0.29

Table 9. cont.

Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
S15339	X	X	X	X	X	X	X	15.98	13.26	5.36	7.57	0.83	0.47	0.34
S15340	13.61	11.04	4.67	6.15	0.81	0.45	0.34	X	X	X	X	X	X	X
S15349	X	X	X	X	X	X	X	66.55	34.77	13.32	12.40	0.52	0.19	0.20
S15350	X	X	X	X	X	X	X	67.98	35.17	17.94	10.96	0.52	0.16	0.52
S15351	73.61	39.22	12.66	16.45	0.53	0.22	0.17	X	40.49	13.39	12.71	X	X	X
S15353	87.34	44.73	12.59	X	0.51	X	0.14	86.57	43.48	9.99	X	0.50	X	0.12
S15354	85.39	41.80	20.70	16.53	0.49	0.19	0.24	X	X	X	X	X	X	X
S15357	78.32	40.84	13.34	10.31	0.52	0.13	0.17	78.03	41.15	15.86	11.95	0.53	0.15	0.20
S15358	X	X	X	X	X	X	X	10.09	7.70	3.23	3.01	0.76	0.30	0.32
S15365	28.14	20.71	7.86	11.12	0.74	0.40	0.28	27.10	19.55	7.80	10.69	0.72	0.39	0.29
S15366	X	X	7.30	8.67	X	X	X	22.69	17.02	5.30	8.67	0.75	0.38	0.23
S15383	X	X	X	X	X	X	X	18.95	14.92	7.42	6.00	0.79	0.32	0.39
S15384	18.58	14.57	6.08	7.73	0.78	0.42	0.33	X	X	X	X	X	X	X
S15390	30.79	21.29	8.95	9.87	0.69	0.32	0.29	X	X	X	X	X	X	X
S15415	55.99	22.97	10.35	3.29	0.41	0.06	0.18	57.87	24.36	10.50	4.38	0.42	0.08	0.18
S15416	59.24	29.19	11.17	8.74	0.49	0.15	0.19	60.67	28.97	11.17	8.74	0.48	0.14	0.18
S15438	18.53	13.67	4.50	7.10	0.74	0.38	0.24	X	X	X	X	X	X	X
S15439	11.20	7.53	2.86	4.58	0.67	0.41	0.26	X	X	X	X	X	X	X
S15440	6.55	5.51	1.66	2.70	0.84	0.41	0.25	X	X	X	X	X	X	X

Table 9. cont.

Specimen Number	RVL	RVH	RVW	RVBL	RVH/L	RVBL/L	RVW/L	LVL	LVH	LVW	LVBL	LVH/L	LVBL/L	LVW/L
S15457	21.26	15.75	4.76	8.32	0.74	0.39	0.22	X	X	X	X	X	X	X
S15464	X	X	X	X	X	X	X	6.19	5.19	1.07	3.19	0.84	0.52	0.17
S15468	110.72	61.83	24.91	X	0.56	X	0.22	X	X	X	X	X	X	X
S15470	37.67	21.05	7.62	4.76	0.56	0.13	0.20	36.83	20.91	7.52	4.76	0.57	0.13	0.20
S15471	81.10	36.11	11.38	9.98	0.45	0.12	0.14	79.38	35.67	13.21	9.98	0.45	0.13	0.17
S15479	13.52	10.10	3.33	6.14	0.75	0.45	0.25	13.49	9.92	2.83	6.14	0.74	0.46	0.21
S15484	21.60	13.64	3.15	8.44	0.63	0.39	0.15	X	X	X	X	X	X	X
S15486	X	X	X	X	X	X	X	9.72	7.64	1.49	4.72	0.79	0.49	0.15
S15487	74.06	46.68	13.62	16.43	0.63	0.22	0.18	X	X	X	X	X	X	X
S15491	X	X	X	X	X	X	X	4.10	3.45	0.68	2.22	0.84	0.54	0.17
S15492	X	X	X	X	X	X	X	7.02	9.32	X	1.63	1.33	0.23	X
S15493	21.24	17.36	7.48	8.84	0.82	0.42	0.35	X	X	X	X	X	X	X
S15505	22.22	16.46	5.85	9.37	0.74	0.42	0.26	22.33	16.14	5.93	9.37	0.72	0.42	0.27
S15508	14.33	10.24	4.08	5.97	0.71	0.42	0.28	X	X	X	X	x	X	X
S15510	16.05	11.98	3.17	7.10	0.75	0.44	0.20	X	X	X	X	X	X	X
S15511	8.05	6.49	1.36	2.80	0.81	0.35	0.17	X	X	X	X	X	X	X
S15512	X	X	X	X	X	X	X	22.19	18.09	8.38	8.84	0.82	0.40	0.38
S15527	82.93	39.59	9.02	19.59	0.48	0.24	0.11	X	X	X	X	X	X	X
S15457	21.26	15.75	4.76	8.32	0.74	0.39	0.22	X	X	X	X	X	X	X

Table 10. Measurements for unknown snails. Xs represent no measurement available. Table X. Measurements for unknown snails. Xs represent no measurement available.

Specimen Number	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
S14233	4.76	X	5.11	X	5.09	1.76	X	3.33	X	1.65	X	X	X	X	X	X	34.68
S14234	4.23	59.01	2.54	1.79	2.52	0.52	1.24	2	1.45	0.88	1.03	1.33	X	X	1.17	1.65	65.61
S14235	5.36	39.57	6.64	3.56	6.57	2.54	3.88	4.03	2.86	1.99	X	2.59	X	X	0.74	1.44	32.55
S14236	5.53	42.72	4.54	2.64	4.51	1.59	2.73	2.93	2.22	1.44	1.35	1.56	1.37	1.62	0.81	1.54	32.62
S14237	3.96	65.14	4.75	2.95	4.74	1.05	1.87	3.69	2.46	1.53	1.64	2.55	1.65	2.57	1.32	1.61	68.6
S14238	3.94	55.87	4.64	3.47	4.62	1.2	2.21	2.38	2.51	X	1.99	2.38	1.93	2.42	1.14	X	X
S14239	3.46	71.09	3.54	2.58	3.53	0.59	1.41	2.94	2.12	1.18	X	1.92	X	X	1.50	1.80	71.5
S14240	3	48.3	4.5	2.62	4.49	1.11	2.28	3.38	2.11	1.48	1.4	2.34	X	X	0.93	1.43	33.9
S14244	5.93	35.76	7.54	3.71	7.51	3.34	5.16	4.16	3.4	X	2.06	2.39	X	X	0.66	X	X
S14246	4.23	48.83	3.68	2.35	X	1.16	2.14	X	2.01	1.35	X	X	X	X	0.94	1.49	44.61
S14247	6	40.28	9.88	5.56	9.86	3.07	6.04	6.78	4.64	3.49	2.97	3.99	X	X	0.77	1.33	49.82
S14255	3.61	62.01	3.45	2.62	3.45	0.69	1.67	2.77	2.1	1.23	1.42	1.78	X	X	1.26	1.71	67.67
S14259	4.83	41.86	5.88	2.88	5.88	1.95	3.22	3.92	2.52	1.87	1.66	2.54	1.61	2.33	0.78	1.35	38.18
S14260	4.43	43.86	4.82	2.7	4.81	1.4	2.6	3.41	2.19	1.67	1.41	2.02	X	X	0.84	1.31	36.13
S14264	5.08	47.43	21.63	8.27	21.58	4.51	6.79	17.07	3.61	6.22	4.66	13.78	X	X	0.53	0.58	41.74
S14269	6.11	46.95	16.09	9.41	15.97	4.42	8.1	11.55	7.29	5.28	5.62	7.79	X	X	0.90	1.38	51.46
S14286	4.88	76.39	23.53	20.48	X	4.91	11.61	18.63	16.68	10.15	11.18	12.16	X	X	1.44	1.64	69.27
S15393	6	32.91	27.19	12.05	27.14	11.22	16.85	15.92	10.15	7.72	X	10.07	X	X	0.60	1.31	29.9
S15395	5	49.93	17.21	10.95	17.21	5.45	9.51	11.76	9.01	6.41	5.94	6.89	X	X	0.95	1.41	42.3
S15396	5	36.71	20.13	9.29	20.17	8.21	12.2	11.96	8.38	6.31	4.83	7.75	X	X	0.69	1.33	27.62
S15399	6	49.23	14.84	7.03	14.83	3.15	5.51	11.68	5.23	2.92	4.04	8.79	4.16	8.84	0.95	1.79	31.02

Table 10. cont.

Specimen Number	#W-MHI (rev)	MSA (in °)	MHI	PWI (MWI)	PHI	PSH1	PSH2 (MSH)	PBH	PSW1 (MSW)	PSW2	PAW	PAH	FAW	FAH	MSW/ MSH %	MSW/ PSW2 %	SWA (in °)
S15400	4	X	4.35	10.2	4.34	X	X	4.34	7.17	3.06	3.86	4.21	X	X	X	2.34	147.64
S15401	4.38	137.29	4.81	9.4	4.81	0.73	1.2	4.07	6.24	3.35	4.17	3.89	X	X	5.20	1.86	131.09
S15403	6.24	45.87	26.65	14.27	26.3	7.98	14.55	18.34	12.64	9.1	7.26	10.92	7.2	11.13	0.87	1.39	42.28
S15405	4.54	52.32	20.55	14.26	22.73	6.73	11.86	16	12.01	8.08	7.28	10.27	7.42	10.5	1.01	1.49	45.27
S15409	5.23	42.07	28.07	14.97	28.06	9.79	16.8	18.27	13.17	10.02	7.88	10.74	X	X	0.78	1.31	36.15
S15411	5.15	48.34	24.05	13.82	24.05	6.6	13.09	17.45	12.01	8.52	8.15	10.22	8.34	11.07	0.92	1.41	43.16
S15465	5.62	46.55	22.93	12.77	22.94	7.48	12.34	15.47	10.8	7.85	7.05	9.81	X	X	0.88	1.38	42.47
S15466	3.5	X	X	5.3	X	X	X	5.88	4.66	3.43	2.81	4.11	X	X	X	1.36	40.48
S15469	4.86	53.24	20.85	12.49	20.78	6.03	10.63	14.75	10.94	7.51	6.66	9.6	X	X	1.03	1.46	47.69
S15473	6	35.62	24.3	11.27	24.31	9.64	15.27	14.67	10.08	7.46	6.17	8.43	X	X	0.66	1.35	27.25

Appendix B. Characters

Table 11. Clam traits for unknown specimens. Question marks represent missing data.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
1	0	0	1	1	1	2	1	2	1	1	0	1	1	0	2	2	1
2	1	1	1	2	1	0	1	1	2	1	1	1	2	1	0	0	0
3	?	?	?	?	?	?	?	?	?	?	?	2	?	?	?	2	2
4	9	9	9	5	5	3	8	3	5	5	3	5	5	5	6	4	4
5	2	2	2	4	4	2	4	2	4	4	2	4	4	4	1	2	1
6	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	5	5
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	2	2	4	4	2	3	2	4	4	2	4	4	3	4	2	2
9	1	1	1	1	1	2	2	2	1	1	2	1	1	1	1	2	2
10	1	1	1	1	?	4	4	?	1	1	4	1	1	2	1	1	1
11	0	0	0	0	0	0	0	?	0	0	0	0	0	3	0	0	0
12	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
13	1	1	1	1	1	1	1	?	1	1	1	1	1	3	1	1	1
14	1	1	1	1	1	1	1	?	1	1	1	1	1	4	1	1	1
15	1	1	1	4	4	2	3	?	4	4	3	4	4	4	3	3	3
16	2	2	2	2	2	1	2	3	2	2	2	2	2	2	2	2	2
17	1	1	1	1	1	1	1	?	1	1	1	1	1	?	1	1	1
18	1	1	1	1	1	?	1	?	1	1	1	1	1	?	1	1	1
19	6	6	6	5	5	6	5	2	5	5	5	5	5	1	?	5	5
20	0	0	0	0	0	3	0	?	0	0	0	0	0	3	0	0	0
21	0	0	0	0	0	3	0	?	0	0	0	0	0	3	0	0	0
22	1	1	1	1	1	1	1	?	1	1	1	1	1	?	1	1	1

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
23	2	2	2	3	3	4	4	3	3	3	4	3	3	3	1	2	2
24	2	2	2	2	2	2	2	?	2	2	2	2	2	1	2	1	1
25	1	1	1	1	?	2	1	?	1	1	1	1	1	1	2	1	1
26	1	1	1	1	1	1	1	?	1	1	1	1	1	1	1	1	1
27	1	1	1	1	1	1	1	?	1	1	1	1	1	1	1	1	1
28	1	1	1	1	1	1	1	?	1	1	1	1	1	1	1	1	1
29	1	1	1	1	1	2	1	?	1	1	1	1	1	1	2	2	2
30	?	?	?	?	?	?	?	?	?	?	?	1	?	?	2	?	?
31	?	?	?	?	?	?	?	?	?	?	?	1	?	?	2	?	?
32	?	?	?	?	1	?	1	?	?	1	1	?	?	?	?	1	?
33	?	?	?	?	2	?	2	?	?	2	2	?	?	?	?	2	?
34	?	?	?	?	2	?	2	?	?	2	2	?	?	1	?	3	?
35	?	?	?	?	1	?	1	?	?	1	1	?	?	1	?	3	?
36	?	?	?	?	1	?	1	?	?	1	1	?	?	1	?	2	?
37	?	?	?	?	2	?	3	?	?	2	3	?	?	1	?	0	?
38	?	?	?	?	2	?	?	?	?	2	?	?	?	2	?	2	?
39	?	?	?	?	2	?	?	?	?	2	?	?	?	2	?	2	?
40	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	2	?
41	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	1	?
42	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	2	?
43	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	3	?
44	?	?	?	?	4	?	?	?	?	4	?	?	?	4	?	1	?
45	?	?	?	?	1	?	?	?	?	1	?	?	?	2	?	1	?
46	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	2	?
47	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	3	?
48	?	?	?	?	3	?	?	?	?	3	?	?	?	1	?	1	?

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
49	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
50	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
51	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
52	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
53	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
54	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
55	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
56	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
57	?	?	?	?	1	?	?	?	?	1	?	?	?	1	?	1	?
58	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
59	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	?	?
60	?	?	?	?	?	?	2	?	?	?	2	?	?	?	?	?	?
61	?	?	?	?	?	?	3	?	?	?	3	?	?	?	?	?	?
62	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	?	?
63	?	?	?	?	?	?	2	?	?	?	2	?	?	?	?	?	?
64	?	?	?	?	?	?	2	?	?	?	2	?	?	?	?	?	?
65	?	?	?	?	?	?	4	?	?	?	4	?	?	?	?	?	?
66	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
67	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
68	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
69	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
70	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
71	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
72	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
73	?	?	?	?	2	?	2	?	?	2	2	?	?	?	?	2	?
74	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
75	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
76	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
77	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
78	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
79	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
80	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
81	?	?	?	?	1	?	?	?	?	1	?	?	?	?	?	?	?
82	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	1	?
83	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	2	?
84	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	1	?
85	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	2	?
86	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	2	?
87	?	?	?	?	?	?	1	?	?	?	1	?	?	?	?	1	?
88	?	?	?	?	2	?	2	?	?	2	2	?	?	3	?	3	?

Table 11. cont.

Character	S15471	S15484	S15486	S15510	S15511	S15512	S15527	S15493	S15505	S15508	S14280	S14291	S14294	S15468	S15464	S15479	S15487
1	2	0	0	0	0	1	2	1	1	0	2	1	1	2	0	1	2
2	0	1	1	1	2	2	1	2	1	1	0	2	1	0	2	2	1
3	2	?	?	?	?	?	?	?	2	?	?	?	?	?	?	2	?
4	4	3	9	5	9	5	3	8	5	5	3	5	5	3	9	2	3
5	2	2	2	4	2	4	2	4	4	4	2	4	4	2	2	2	2
6	5	2	2	2	2	2	2	2	2	1	2	2	2	2	2	2	2
7	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	2	2	2	4	2	4	2	3	4	3	2	4	4	2	2	2	2
9	2	2	1	1	1	1	2	2	1	1	2	1	1	2	1	1	2

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
10	1	?	1	1	1	1	?	4	1	2	4	1	?	4	1	1	?
11	0	0	0	0	0	0	?	0	0	3	0	0	0	0	0	0	?
12	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	0	?
13	1	1	1	1	1	1	?	1	1	3	1	1	1	1	1	?	?
14	1	1	1	1	1	1	?	1	1	4	1	1	1	1	1	1	?
15	3	?	1	4	1	4	?	3	4	4	2	4	4	2	1	3	?
16	2	3	2	2	2	2	3	2	2	2	1	2	2	1	2	3	3
17	1	1	1	1	1	1	?	1	1	?	1	1	1	1	1	1	?
18	1	1	1	1	1	1	?	1	1	?	?	1	1	?	1	4	?
19	5	1	6	5	6	5	2	5	5	1	6	5	5	6	6	6	2
20	0	0	0	0	0	0	?	0	0	3	3	0	0	3	0	0	?
21	0	0	0	0	0	0	?	0	0	3	3	0	0	3	0	0	?
22	0	0	0	0	0	0	?	0	0	0	0	0	0	0	0	0	?
23	2	1	2	3	2	3	3	4	3	3	4	3	3	4	2	3	3
24	1	1	2	2	2	2	?	2	2	1	2	2	2	2	2	1	?
25	1	?	1	1	1	1	?	1	1	1	2	1	?	2	1	0	?
26	1	?	1	1	1	1	?	1	1	1	1	1	1	1	1	2	?
27	1	?	1	1	1	1	?	1	1	1	1	1	1	1	1	1	?
28	1	?	1	1	1	1	?	1	1	1	1	1	1	1	1	1	?
29	2	?	1	1	1	1	?	1	1	1	2	1	1	2	1	1	?
30	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	1	?
31	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	1	?
32	1	?	?	?	?	?	?	1	?	?	?	?	?	?	?	?	?
33	2	?	?	?	?	?	?	2	?	?	?	?	?	?	?	?	?
34	3	?	?	?	?	?	?	2	?	1	?	?	?	?	?	?	?
35	1	?	1	1	1	1	?	4	1	2	4	1	?	4	1	1	?

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
36	3	?	?	?	?	?	?	1	?	1	?	?	?	?	?	?	?
37	2	?	?	?	?	?	?	1	?	1	?	?	?	?	?	?	?
38	0	?	?	?	?	?	?	3	?	1	?	?	?	?	?	2	?
39	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
40	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
41	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
42	1	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
43	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
44	3	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
45	1	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
46	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
47	1	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
48	2	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
49	3	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
50	1	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
51	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
52	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
53	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
54	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
55	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
56	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
57	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
58	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
59	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
60	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
61	?	?	?	?	?	?	?	1	?	1	?	?	?	?	?	?	?

Table 11. cont.

Character	S11702	S11705	S11772	S15334	S15336	S15354	S15390	S15355	S15329	S15330	S15332	S15365	S15366	S15358	S15415	S15416	S15470
62	?	?	?	?	?	?	?	2	?	3	?	?	?	?	?	?	?
63	?	?	?	?	?	?	?	3	?	3	?	?	?	?	?	?	?
64	?	?	?	?	?	?	?	1	?	1	?	?	?	?	?	?	?
65	?	?	?	?	?	?	?	2	?	1	?	?	?	?	?	?	?
66	?	?	?	?	?	?	?	2	?	1	?	?	?	?	?	?	?
67	?	?	?	?	?	?	?	4	?	4	?	?	?	?	?	?	?
68	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
69	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
70	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
71	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
72	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
73	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
74	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
75	?	?	?	?	?	?	?	2	?	?	?	?	?	?	?	?	?
76	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
77	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
78	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
79	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
80	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
81	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
82	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
83	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
84	?	?	?	?	?	?	?	1	?	?	?	?	?	?	?	?	?
85	?	?	?	?	?	?	?	1	?	?	?	?	?	?	?	?	?
86	?	?	?	?	?	?	?	1	?	?	?	?	?	?	?	?	?
87	?	?	?	?	?	?	?	1	?	?	?	?	?	?	?	?	?
88	?	?	?	?	?	?	?	2	?	3	?	?	?	?	?	?	?

Table 12. Snail characters for unknown specimens. Question marks represent missing data.

Character	S14233	S14234	S14235	S14236	S14237	S14238	S14239	S14240	S14244	S14246	S14247	S14255	S14259	S14260	S14264	S14269	S14286
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1
2	1	0	1	1	0	0	0	0	1	0	2	0	1	0	1	2	1
3	?	1	1	1	1	1	1	1	0	1	1	1	0	1	0	1	1
4	0	1	0	1	1	0	1	1	0	1	0	0	0	1	0	1	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	1
6	0	0	0	0	0	0	0	?	0	0	1	0	0	?	?	0	?
7	2	3	1	2	4	3	4	3	1	2	2	3	1	2	5	3	4
8	?	1	0	1	2	1	2	1	0	1	1	2	1	?	?	1	?
9	?	?	?	?	?	?	?	?	?	?	?	?	?	1	1	?	2
10	2	1	2	2	1	1	1	2	3	2	2	2	3	2	2	2	1
11	1	0	1	1	0	1	0	1	2	?	1	0	1	1	0	0	0
12	?	1	0	1	1	1	2	1	0	1	1	1	1	1	0	1	1
13	2	2	1	2	1	2	1	2	1	2	2	2	1	1	1	2	2
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
15	?	?	1	2	0	1	2	2	2	?	2	2	2	2	0	2	2
16	2	1	1	2	1	2	1	2	1	2	2	2	1	2	1	2	2
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12. cont.

Character	S14233	S14234	S14235	S14236	S14237	S14238	S14239	S14240	S14244	S14246	S14247	S14255	S14259	S14260	S14264	S14269	S14286
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	?	2	?	1	0	0	0	1	1	?	1	1	1	1	1	1	1
26	?	2	2	2	2	1	2	2	4	?	2	2	2	2	1	2	3
27	?	2	1	2	0	1	?	2	?	?	1	?	0	0	0	2	?
28	?	?	1	2	2	0	0	?	0	?	0	0	0	?	2	2	0
29	?	?	?	2	1	2	?	?	?	?	?	?	1	?	?	?	?
30	?	1	2	2	1	2	?	1	2	?	1	2	1	1	0	1	2
31	1	2	1	1	2	?	2	1	?	1	1	2	1	1	1	1	2
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 12. cont.

Character	S15393	S15395	S15396	S15399	S15400	S15401	S15403	S15405	S15409	S15411	S15465	S15466	S15469	S15473	S15489	S15490
1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1
2	1	1	1	2	0	0	2	1	1	1	1	0	1	2	1	0
3	0	1	0	0	2	2	1	1	1	1	1	?	1	0	1	?
4	0	1	1	0	?	0	1	1	1	1	?	0	1	?	?	0
5	1	1	1	1	1	0	1	1	1	1	0	1	0	1	1	1
6	?	?	?	?	?	0	?	?	?	?	0	?	?	?	?	?
7	2	2	3	5	4	4	2	2	2	3	2	2	2	1	2	1
8	?	?	?	?	?	2	?	?	?	?	1	?	?	?	?	?
9	1	1	0	1	?	?	1	1	1	1	?	?	1	0	1	?
10	2	2	2	3	0	0	2	2	2	2	2	2	2	3	2	3
11	1	1	2	1	?	1	1	1	1	0	1	?	1	1	1	?

Table 12. cont.

Character	S15393	S15395	S15396	S15399	S15400	S15401	S15403	S15405	S15409	S15411	S15465	S15466	S15469	S15473	S15489	S15490	S15393
12	0	1	0	1	2	2	1	1	1	1	1	?	1	0	1	?	
13	1	1	1	0	3	3	2	2	2	2	2	2	2	1	2	1	
14	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	
15	0	?	0	2	?	2	1	2	2	0	2	2	2	?	2	1	
16	2	2	1	0	3	3	2	2	2	2	2	2	2	1	2	1	
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
23	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
25	?	?	1	?	2	2	1	1	1	1	1	?	?	?	1	?	
26	1	?	2	1	?	0	2	2	2	2	2	2	2	?	2	2	
27	?	?	0	?	?	?	3	2	0	0	?	?	?	?	3	?	
28	?	?	0	3	?	?	2	2	0	2	?	0	0	?	0	0	
29	?	?	?	0	?	?	1	1	?	1	?	?	?	?	?	?	
30	?	?	?	0	?	2	1	1	1	2	1	1	1	1	1	1	
31	0	1	1	1	2	2	1	1	1	1	1	1	1	0	1	0	
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
34	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	